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AN EVALUATION OF VARIOUS DEPTH TRANSDUCERS FOR POTENTIAL APPLICATION TO SUBMARINE COMMUNICATION BUOYS

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

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AN EVALUATION OF VARIOUS DEPTH TRANSDUCERS FOR POTENTIAL APPLICATION TO SUBMARINE COMMUNICATION BUOYS,

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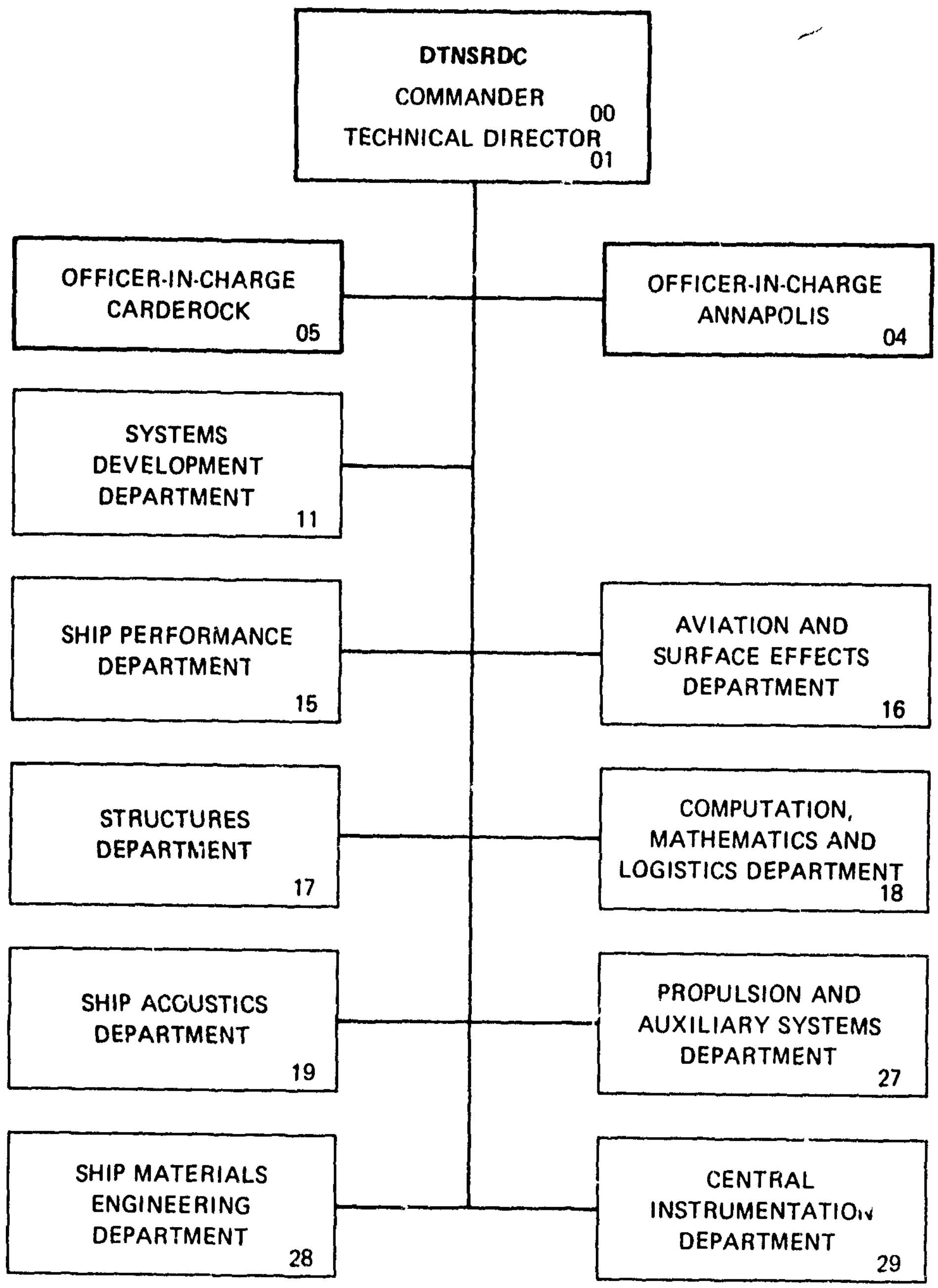

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Various pressure gages were experimentally evaluated for potential use as depth sensors in submarine communications buoys. Accuracy, hysteresis and linearity were determined over a temperature range as well as under simulated long-term cycling. The effect of depth-gage mounting location on communications and navigational accuracy is analyzed, and methods of over-pressure protection for shallow-depth gages are discussed. Results indicated that the
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AERO-MECHANISM, SENSOTEC, and CONTRAC gages are the best candidates for buoy applications. The mounting location of the depth-gage can adversely affect the navigational accuracy.

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NOTATION

A (subscript)	Refers to an arbitrary point in the buoy
B (subscript)	Refers to the pressure transducer
D_1	Distance between points A and B in the fore-aft plane
D_2	Distance between points A and B in the athwartship plane
x	Longitudinal direction
y	Vertical direction
z	Transverse direction
X diff, Y diff, X diff	Change in relative coordinates between points A and B when the buoy moves from a zero-pitch zero-roll angle to some arbitrary attitude
X-Y-Z system	Coordinate system fixed to the buoy with the X-direction parallel to the buoy keel
X^1-Y^1-Z^1 system	Coordinate system fixed in inertial space with the X-direction parallel to the natural horizon
ΔX, ΔY, ΔZ	Relative coordinates between points A and B in the X-Y-Z coordinate system
ΔX^1, ΔY^1, ΔZ^1	Relative coordinates between points A and B in the X^1-Y^1-Z^1 coordinate system
α	Angle between the X^1 direction and the buoy keel (buoy pitch angle)
β	Angle between the X^1 direction and the line between points A and B
δ	Angle between the Z direction and the line between points A and B
ϕ	Angle between Z^1 direction and the buoy upper surface
ψ	Angle between the Z^1 direction and the line between points A and B
θ	Angle between the X direction and the line between points A and B

ABSTRACT

Various pressure gages were experimentally evaluated for potential use as depth sensors in submarine communications buoys. Accuracy, hysteresis and linearity were determined over a temperature range as well as under simulated long-term cycling. The effect of depth-gage mounting location on communications and navigational accuracy is analyzed, and methods of overpressure protection for shallow-depth gages are discussed. Results indicate that the AERO-MECHANISM, SENSOTEC, and CONRAC gages are the best candidates for buoy applications. The mounting location of the depth-gage can adversely affect the navigational accuracy.

ADMINISTRATIVE INFORMATION

The evaluation described in this report was funded by the Naval Electronics Systems Command Program Element 11402N, Task Area X0793310, David W. Taylor Naval Ship Research and Development Center Work Unit 1-1548-081.

INTRODUCTION

The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) was requested by the Naval Electronic Systems Command (NAVELEX) to evaluate various pressure transducers for potential application to submarine communications buoys. Specifically, the investigation was to determine transducer accuracy and repeatability for reading water depth under simulated long-term cycling and over the expected operational temperature range.

To maintain reliable communications while remaining deeply submerged, SSBN submarines are equipped with towed communications buoys. These are hydrodynamic lifting bodies containing various antennas and the associated signal processing equipment. The buoy is connected to the submarine by a towcable, which also relays the various communications and instrumentation signals. The buoy operates in two distinct depth regimes. When the buoy is on the submarine, it is in a deep-depth regime. During actual communications, the buoy operates in a shallow-depth regime, just beneath the water surface. The buoy depth can be set for various depth ranges and is controlled by reeling or unreeling cable from a winch mounted in the submarine. In the shallow-depth regime, a more accurate depth measurement is required since communication signal strength is a function of submerged depth. The buoy depth signal is used as input logic to various control systems. These include a system for changing the cable winching rate from fast to slow when the buoy reaches a depth of 50 ft (15 m). The depth signal is used also to arm the buoy destruct system as well as to control the cable winch. Therefore, the buoy requires a depth-measuring system with a large overall range as well as high accuracy in the shallow depths.

Currently, POSEIDON submarines are equipped with the AN/BRA-8C buoy, which uses a combination of deep and shallow depth transducers manufactured by AERO-MECHANISM, INC. The TRIDENT submarine will be equipped with the TRIDENT (AN/BRR-6) buoy which uses a dual-transducer depth-measuring system manufactured by the CONRAC corporation. Both the AN/BRA-8C and the TRIDENT buoys have undergone at-sea evaluations for extended periods.

Experience with these transducers has revealed several problem areas requiring investigation. At unpredictable intervals, the depth indication has been lost or exhibited large errors. The temperature of the buoy's operating medium can change over a large range and this also affects depth-gage accuracy. When the buoy is being towed at shallow depths, it is often in the presence of waves. As waves pass over the buoy, the pressure constantly changes, resulting in long-term cycling of the depth gage. It has been observed that depth-gage performance changes as time in service increases. Since the shallow-depth gages do not have an operational range sufficient to cover the submarine's operation depth, a blanking valve is required to prevent overpressurization and damage to the gages when the buoy is operating in the deep-depth regime. Problems have arisen with respect to such a blanking valve used in the AERO-MECHANISM gage. Finally, the effects of mounting location of the gages on the buoy depth signal for various buoy motions and the resulting errors need to be determined to ascertain the effects on communications and navigational accuracy.

This evaluation was conducted in an attempt to solve these problems. As the POSEIDON submarines are scheduled to be fitted with the new POSEIDON buoy, replacing the existing AN/BRA-8C buoy, it is desirable to use as much as possible of the circuitry that has already been developed for the TRIDENT buoy. This includes the depth gages and processing circuitry, if feasible. This investigation examined the AERO-MECHANISM and CONRAC gages, as well as four additional depth gages suggested as a result of similar work performed at DTNSRDC.

The gages were manifolded together and subjected to various temperature cycles and simulated long-term pressure cycles by using a pressure simulation apparatus with an automatic cycling feature, in conjunction with an oven and a freezer. The resulting data were statistically analysed and gage accuracy, linearity, and several other statistical quantities were determined. A survey of available overpressure protection devices was made. The resulting devices are analyzed, along with suggested modifications. Finally, a theoretical analysis of the effect of depth-gage mounting location based on trigonometric relationships in the buoy was completed.

This report presents the results of the cycling and accuracy studies both graphically and in tables. Parameters significantly affecting depth-gage performance are identified. The effect of temperature variation on gage accuracy is reported and the effect of long-term cycling is given. Details of the overpressure protection devices are explained, and recommendations are made as to further development. The equations for the mounting location analysis are presented and an example of their use is given. Finally, the computer-generated results of the statistical analysis of the pressure versus gage output relationship are tabulated in the appendix.

DEPTH TRANSDUCERS

Seven depth transducers were evaluated. The transducers chosen are either currently used in communications buoys or are being considered for future systems. The AERO-MECHANISM gage is currently used in the AN/BRA-8C buoy. The gage consists of separate low- and high-pressure potentiometric sensors connected by a blanking valve (overpressurization protection mechanism) which limits the pressure to the low-pressure sensor. The CONRAC gage is used in the TRIDENT AN/BRR-6 buoy. The SPARTON-SOUTHWEST gage was the first gage used in the TRIDENT buoy but was replaced by the CONRAC gage due to inconsistent and undependable performance. The SENSOTEC gage is being used successfully in another project at DTNSRDC. The FOXBORO gage was recommended by virtue of its small size, low cost and use of a silicon diaphragm for improved response. Two similar FOXBORO gages were evaluated for comparative purposes. The BELL & HOWELL gage was suggested also for possible application in this program. The gages, their ranges and requirements, are listed in Table 1.

(U) TABLE 1 - DEPTH GAGE CHARACTERISTICS

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Depth Gage	Transducer Type	Pressure psig	Range Megapascals	Input Voltage	Output	Compensated Temperature Range
AERO-MECHANISM	Potentiometer	0-1000	0-6.9	Not required	Ohms	$0^{o}C$ to $50^{o}C$
SPARTON SOUTHWEST	Potentiometer	0-500	0-3.4	+5	Volts	$-54^{o}C$ to $121^{o}C$
BELL & HOWELL	Strain-Gage	0-500	0-3.4	+10	Volts	$-54^{o}C$ to $121^{o}C$
SENSOTEC	Strain-Gage	0-750	0-5.2	+12	Volts	$-1^{o}C$ to $204^{o}C$
CONRAC	Piezo-Resistive	0-500	0-3.4	+28	Volts	$-15^{o}C$ to $38^{o}C$
FOXBORO	Strain-Gage	0-1000	0-6.9	+8	Volts	$-1^{o}C$ to $204^{o}C$

Based on previous depth gage calibrations, the relationship between pressure and the output signal is nominally linear and is expressed by the equation:

$$\text{Pressure} = A * \text{output} + B \quad (1)$$

where output is either volts or ohms, A is the gage sensitivity (psi/ohm or psi/volt), and B is the zero offset (volts or ohms).

EXPERIMENTAL APPARATUS AND PROCEDURES

The gages were evaluated for their performance characteristics when exposed to temperature extremes and pressure cycling. The characteristics of the overpressure protection devices were evaluated also using the apparatus and procedures in the following sections.

DEPTH-GAGE ACCURACY AND TEMPERATURE EFFECTS

The experimental apparatus is shown schematically in Figure 1. A deadweight pressure calibrator is used to apply a known pressure to all the gages simultaneously through a manifold block. Various combinations of accurately-known calibration weights are placed on a piston of known cross-sectional area supported by hydraulic oil. The resulting pressures are accurate to within 0.1 percent of the desired pressure. The pressure calibrator is shown in Figure 2. Pressure is increased in 10 psig (69 kPa) increments between 0 and 100 psig (690 kPa) and in 50 psig (345 kPa) increments between 100 and 650 psig (690 and 4480 kPa), and then back to zero with the same increments. Several cycles were applied at room temperature, in an electric oven and in a freezer. Experimental conditions are summarized in Table 2. The gages were coupled to the manifold block with 1/4-inch copper tubing, as shown in Figure 3. The three gages with a 500 psig (3.4 MPa) range were all placed on one tube with a valve used to close the tube at pressures above 500 psig (3.4 MPa). The gage outputs were read on digital voltmeters accurate to ± 0.001 volt as calibrated by a National Bureau of Standards approved millivolt standard ± 0.1 degree Celsius voltage generator. The temperature was determined to ± 0.1 degree Celsius with a nickel-chromium thermocouple and read on a digital voltmeter. The immersion fluid used for the calibrations was hydraulic fluid.

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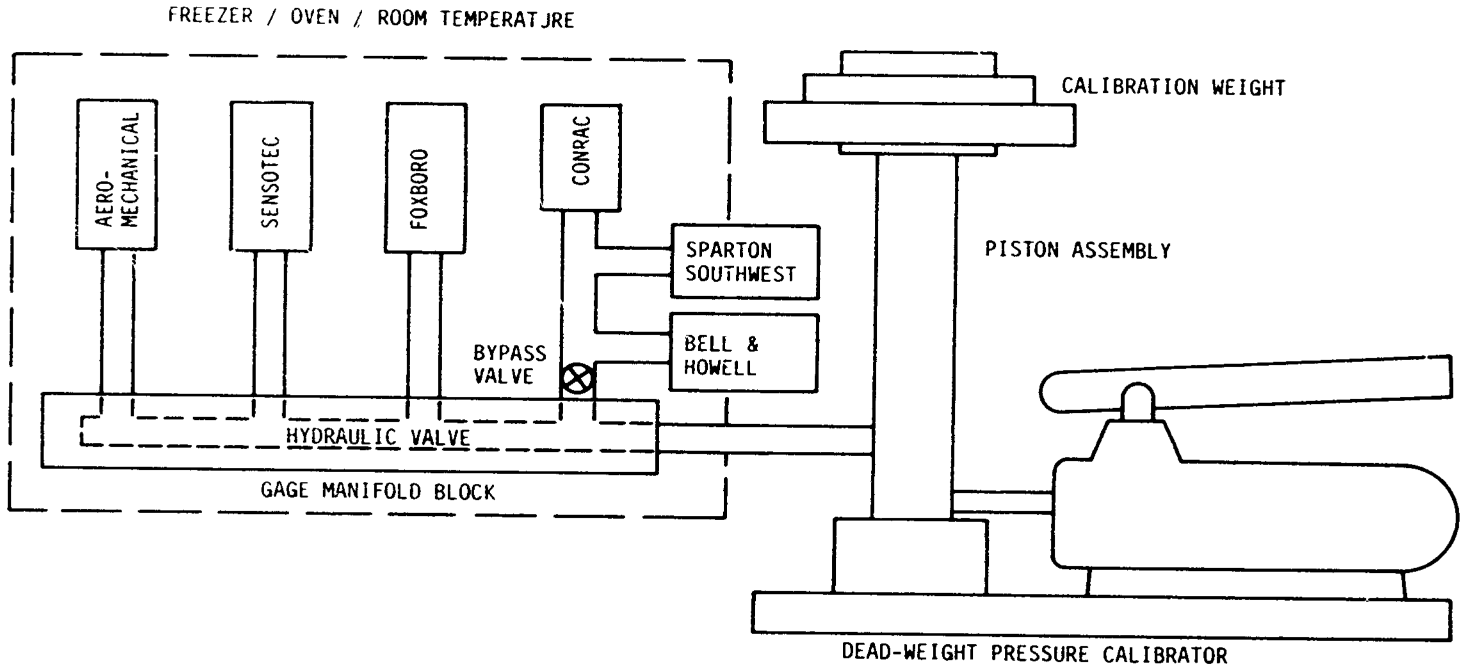
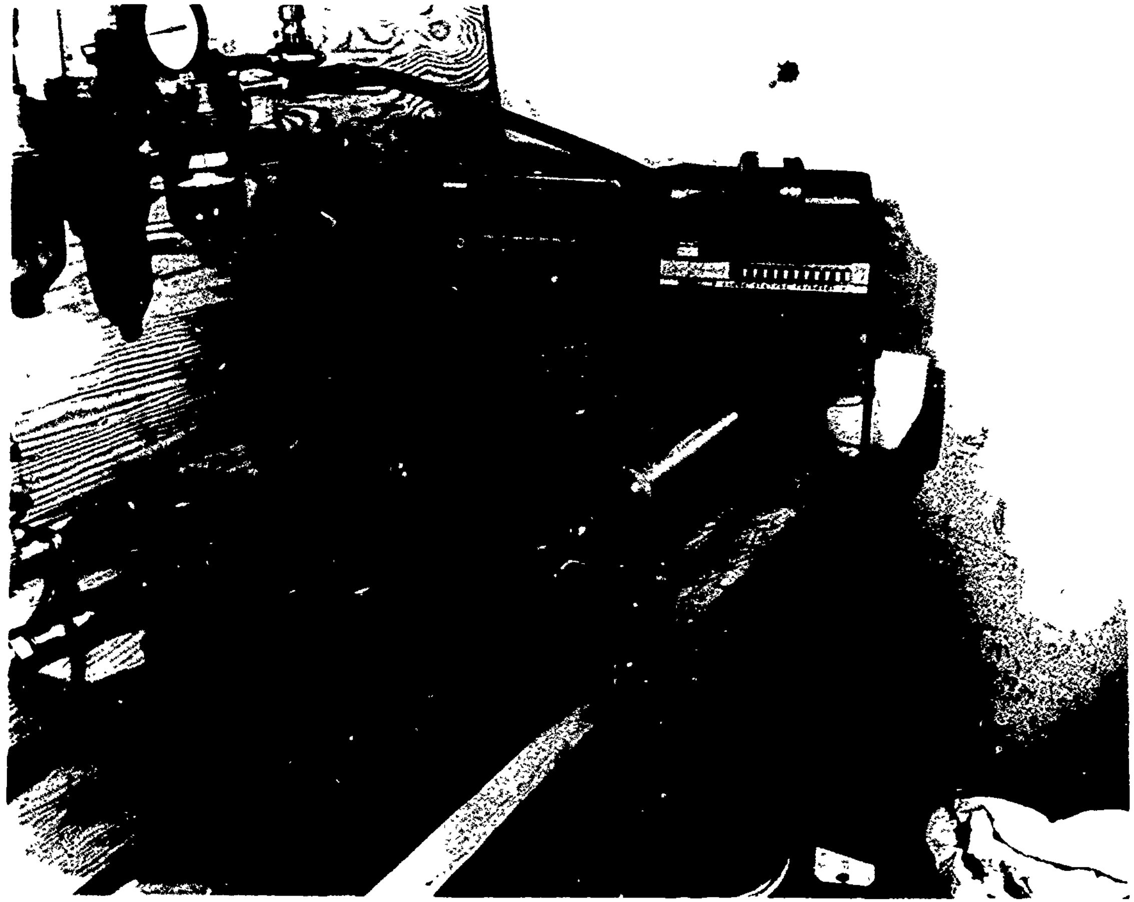


(U) **Figure 1 - Depth-Gage Calibration Apparatus**



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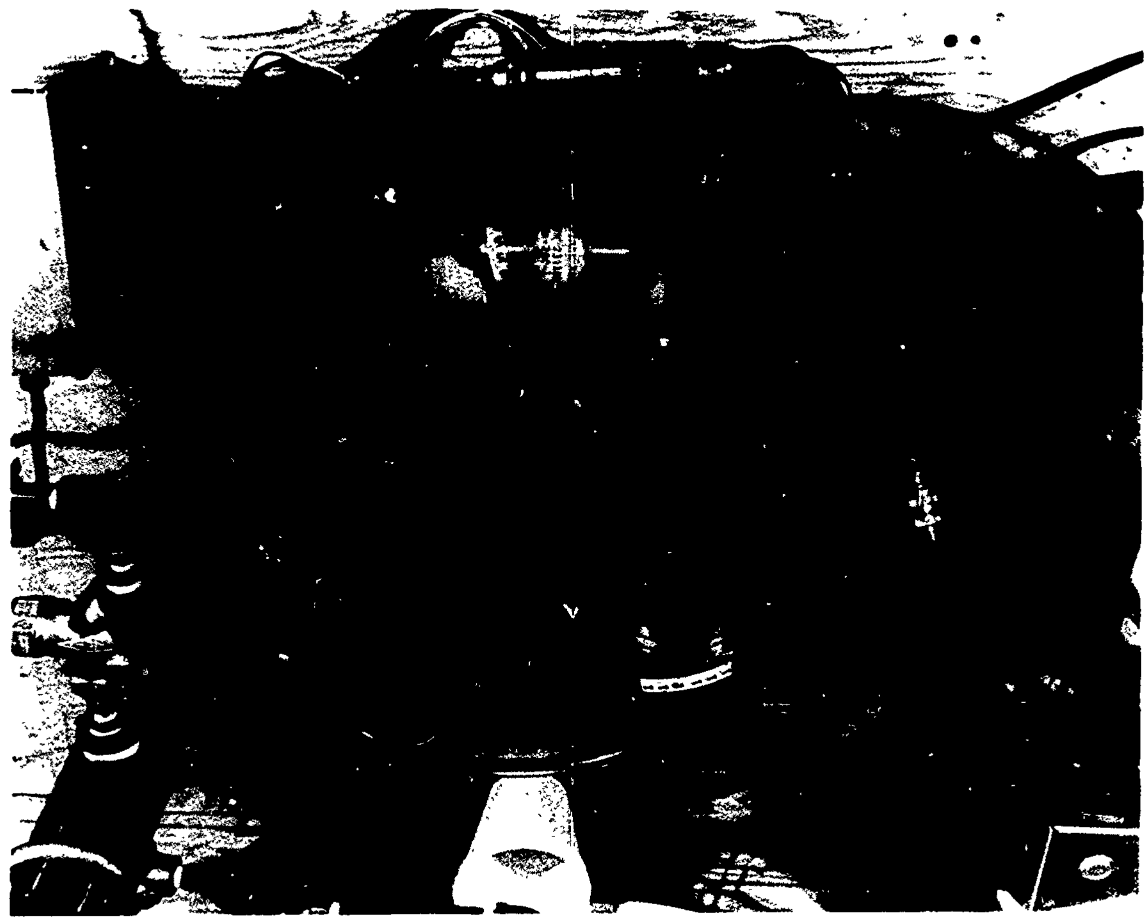
(U) Figure 2 - **Deadweight Pressure Calibrator and Voltmeter Arrangement**



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(U) Figure 3 - Depth Transducer and Minifold Block

(U) TABLE 2 - EXPERIMENTAL CONDITIONS FOR TEMPERATURE VARIATION ANALYSIS

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Temperature	Temperature	No. of Pressure Cycles
C $\pm$0.1 C	F $\pm$0.2 F	
-15	5.0	3
24	75.2	5
31	87.8	2
38	100.4	2
50	122.0	2

Upon completion of the calibration cycles, a computerized first-order least-squares equation was fitted to each set of common temperature cycles. Based on the fitted equation, the sensitivity and zero-offset for each temperature were determined, as well as the maximum and average deviations of the measured data from the fitted line.

EFFECTS OF SIMULATED LONG-TERM CYCLING

To provide realistic conditions for evaluating gage survival, 2 years of actual at-sea operations were simulated since this would be a reasonable length of time to expect accurate transducer operation. Based on a deployment rate of six times per year and simulating the actual winching rates of 50 and 150 feet per minute (15 and 46m/s), the schedule of testing shown in Table 3 was developed. The sequence of four pressure ranges required 1 week to complete, and the entire sequence was repeated for 4 weeks.

An automatic cycling system was constructed using a combination of pneumatic and hydraulic componenets to vary the pressure. The maximum pressure, the rate of change of pressure, and the time per cycle could be controlled. A dead-weight pressure calibrator was also incorporated, and a calibration was performed on all of the gages once each day, with a

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(U) TABLE 3 - SIMULATED LONG-TERM CYCLING SCHEDULE
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Pressure Range psi	Pressure Range mpa	Equivalent Winch Rate (Rate of Ascent or Descent)	Total Cycles Per Week*
0-10	0.07	4.5 ft/sec (10 sec/cycle)	25,000
0-200	1.37	3.0 ft/sec (5 min/cycle)	264
0-500	3.44	2.5 ft/sec (15 min/cycle)	4
0-650	4.48	2.5 ft/sec (20 min/cycle)	4
* Total cycles after 4 weeks = 101,088			

complete calibration performed at the end of each week. The experimental apparatus is shown in Figure 4.

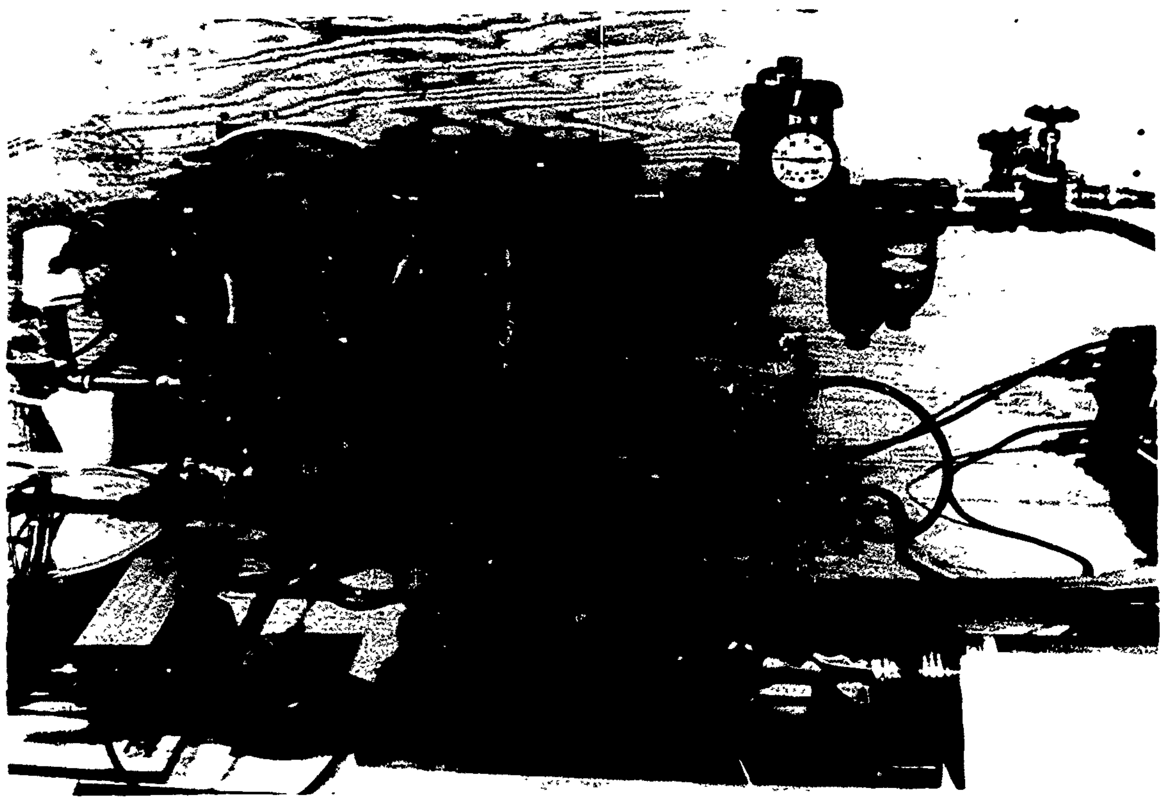
For each gage, the calibration cycles performed at the end of each week were analyzed as described for Depth-Gage Accuracy and Temperature Effects. With this procedure, the degradation of gage accuracy and the change in fitting coefficients with number of cycles were determined.

A SURVEY OF OVERPRESSURE PROTECTION DEVICES

Inquiries were directed to the manufacturers of depth gages evaluated in this project requesting design details or suppliers of overpressure protection devices. Most manufacturers neither made nor supplied such a device but would design one upon request. CONRAC Corp. did produce such a device but claimed it was proprietary and would not release details. Details of another mechanism were obtained from a previous purchase for another project by another group at DTNSRDC. AERO-MECHANISM, Inc. did provide drawings on their overpressure protection device. Thus, only two devices will be discussed.

DEPTH-GAGE MOUNTING LOCATION ANALYSIS

The analysis of the effect of depth-gage mounting location incorporates several assumptions. First, since the depth transducer pressure port is inside the buoy, and since most of the buoy's volume is occupied



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(U) Figure 4 - Long-Term Cycling Apparatus by buoyancy tanks, syntactic foam and instrument cans, it is assumed that there are no dynamic flow patterns near the depth-transducer. This implies that the depth indicated by the transducer is solely the static water pressure for that given depth. The second assumption is that buoy pitch angle is measured as the angle between the horizon and the buoy keel. The third assumption is that at a roll angle of zero, the upper surface of the buoy in the transverse direction is parallel to the horizon.

Based on these assumptions and an analysis of the buoy geometry, the relative positions of the depth-transducer and an arbitrary point in the buoy can be determined for any combination of buoy pitch and roll angles. Once these positions have been determined, the effect of the depth difference on calculated auxiliary antenna floating length and submerged trail distance can be calculated. An example of the calculations for the POSEIDON buoy is given in Appendix B.

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RESULTS AND DISCUSSION

The results of each performance evaluation are discussed in the following sections.

DEPTH-GAGE ACCURACY AND TEMPERATURE EFFECTS

The results of the sensitivity and offset calculations for this phase of the depth-gage evaluation are given in Tables 4, 5, 6 and 7 in Appendix A and are presented graphically in this section. The tables present the results of the data-fitting analysis. For each gage listed, the following information is given:

a. The maximum operating pressure (psig)

b. The coefficients of the first-order least squares fit:

Pressure = A * output + B

where output = ohms for the Aero-Mechanism gage and volts for all other gages and A is the gage sensitivity (psi/volt or psi/ohm) and B is the zero offset (volts or ohms)

c. The correlation coefficient (this indicates the degree to which the data fit a straight line. A perfect fit has a correlation coefficient of 1.000.)

d. The variance in psig, which is an estimate of the standard deviation of the data from the fitted line.

e. The maximum deviation from the fitted line in psig.

f. The maximum deviation expressed as a percent of the gages' operating range.

Two calibrations were performed for each temperature to account for changes in the gage characteristics in different pressure ranges. These calibrations are:

1. 0-30 psig (0-206 kPa) equivalent to 0-68 ft (0-21m) depth of seawater.
2. 0-650 psig (0-4.48 MPa) equivalent to 0-1467 ft (0-447m) depth of seawater.

The data from Tables 6 and 7 of the Appendix were used in plotting Figures 5 to 11, which show the effects of temperature on each gage. The upper graphs show the zero-shift B while the lower graphs show the sensitivity A.

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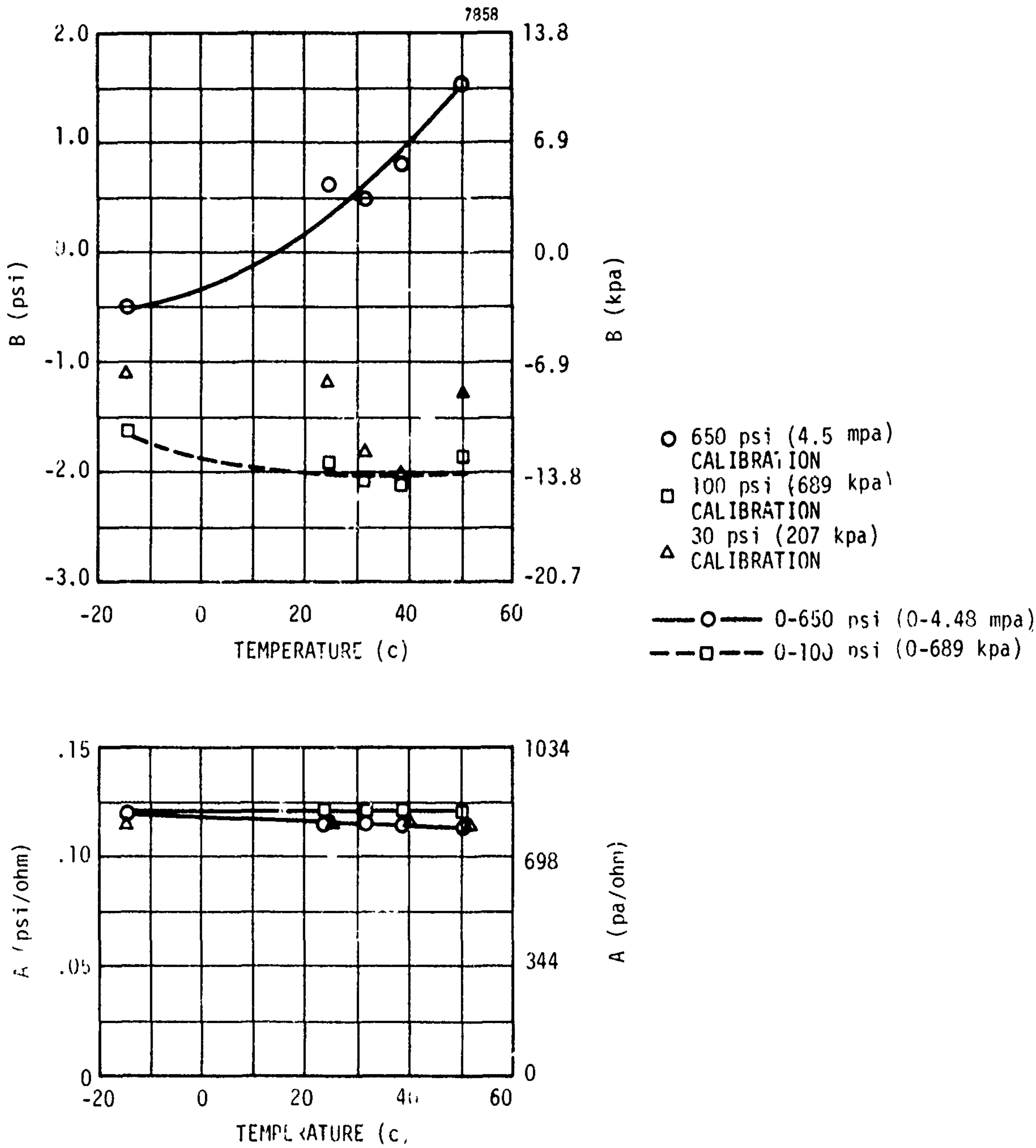

(U) Figure 5 - Sensitivity and Offset as Functions of Temperature for the AERO-MECHANISM Gage

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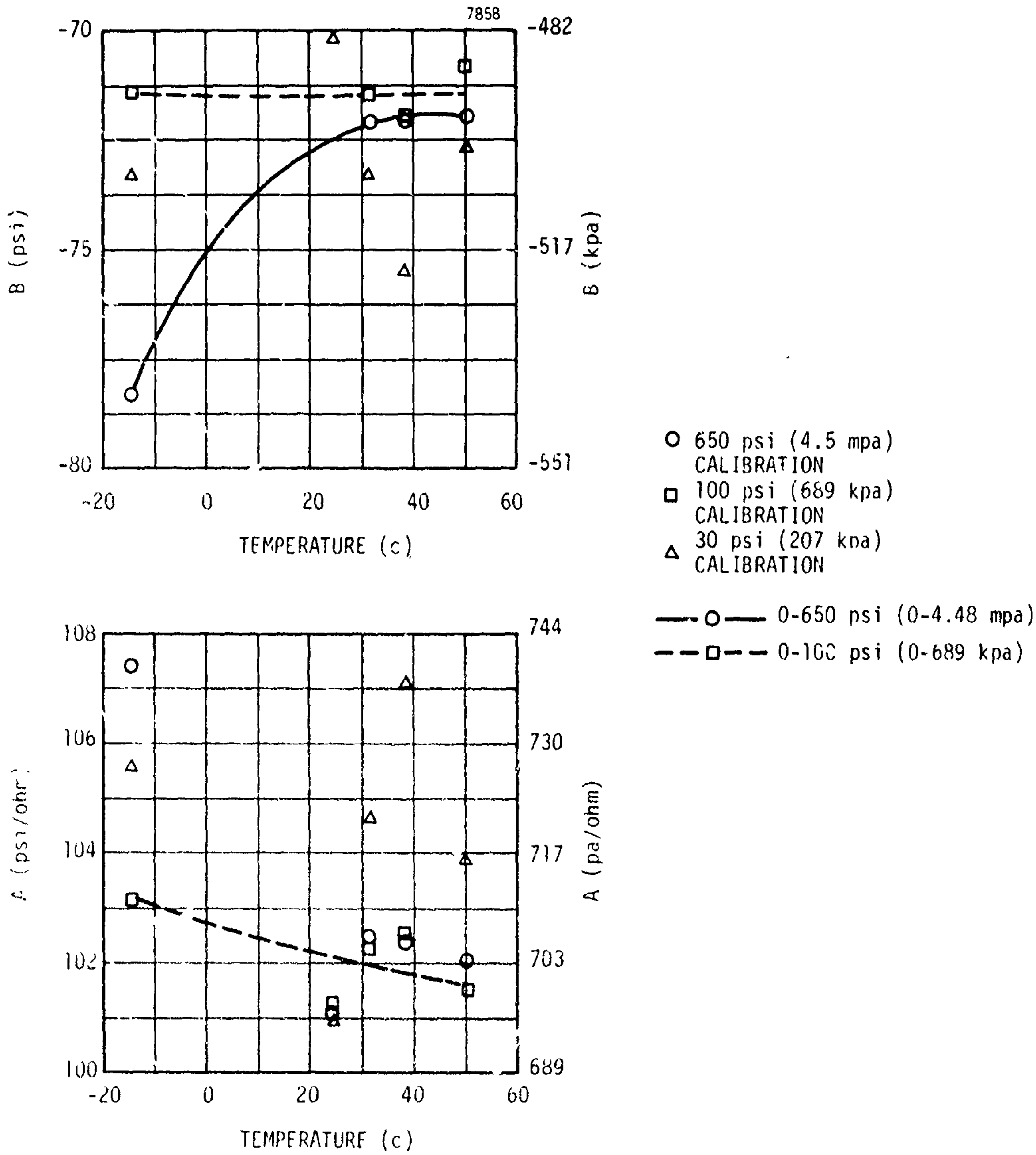

(U) Figure 6 - Least-Squares Fitting Coefficients as a Function of Temperature for the SPARTON-SOUTHWEST Gage

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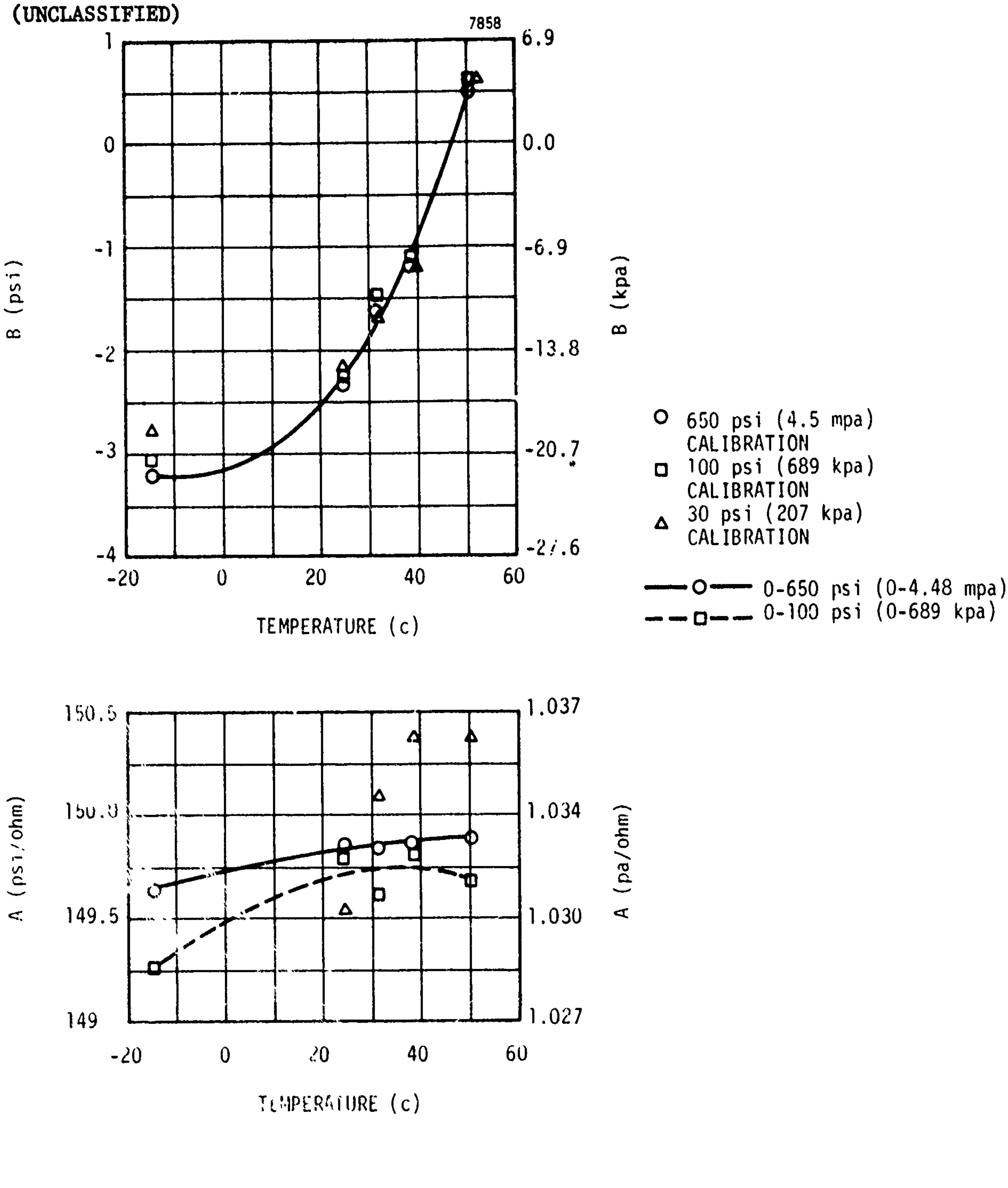

(U) Figure 7 - Least-Squares Fitting Coefficients as a Function of Temperature for the SENSOTEC Gage

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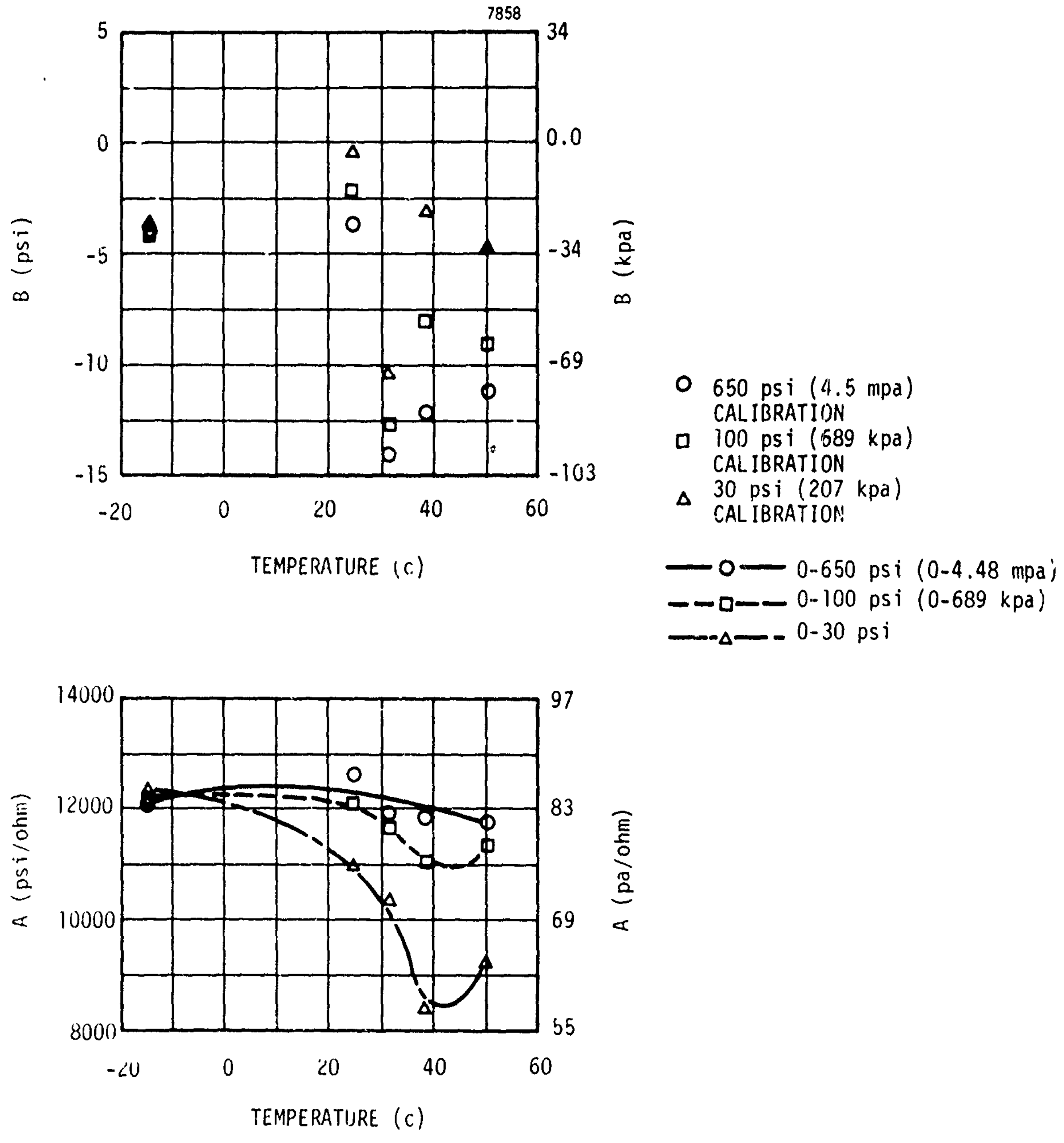

(U) Figure 8 - Least-Squares Fitting Coefficients as a Function of Temperature for the BELL & HOWELL Gage

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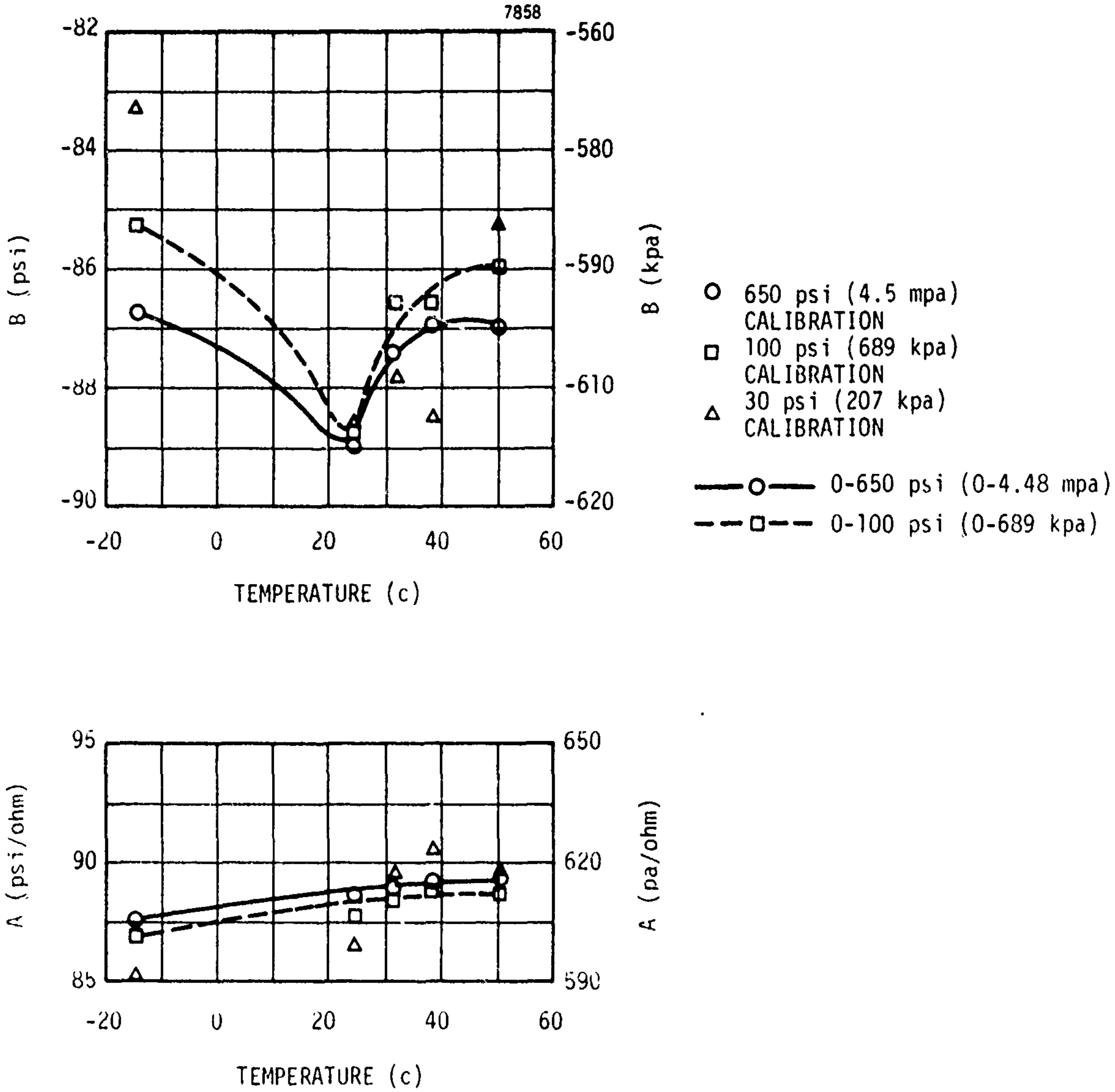

(U) Figure 9 - Least-Squares Fitting Coefficients as a Function of Temperature for the CONRAC Gage

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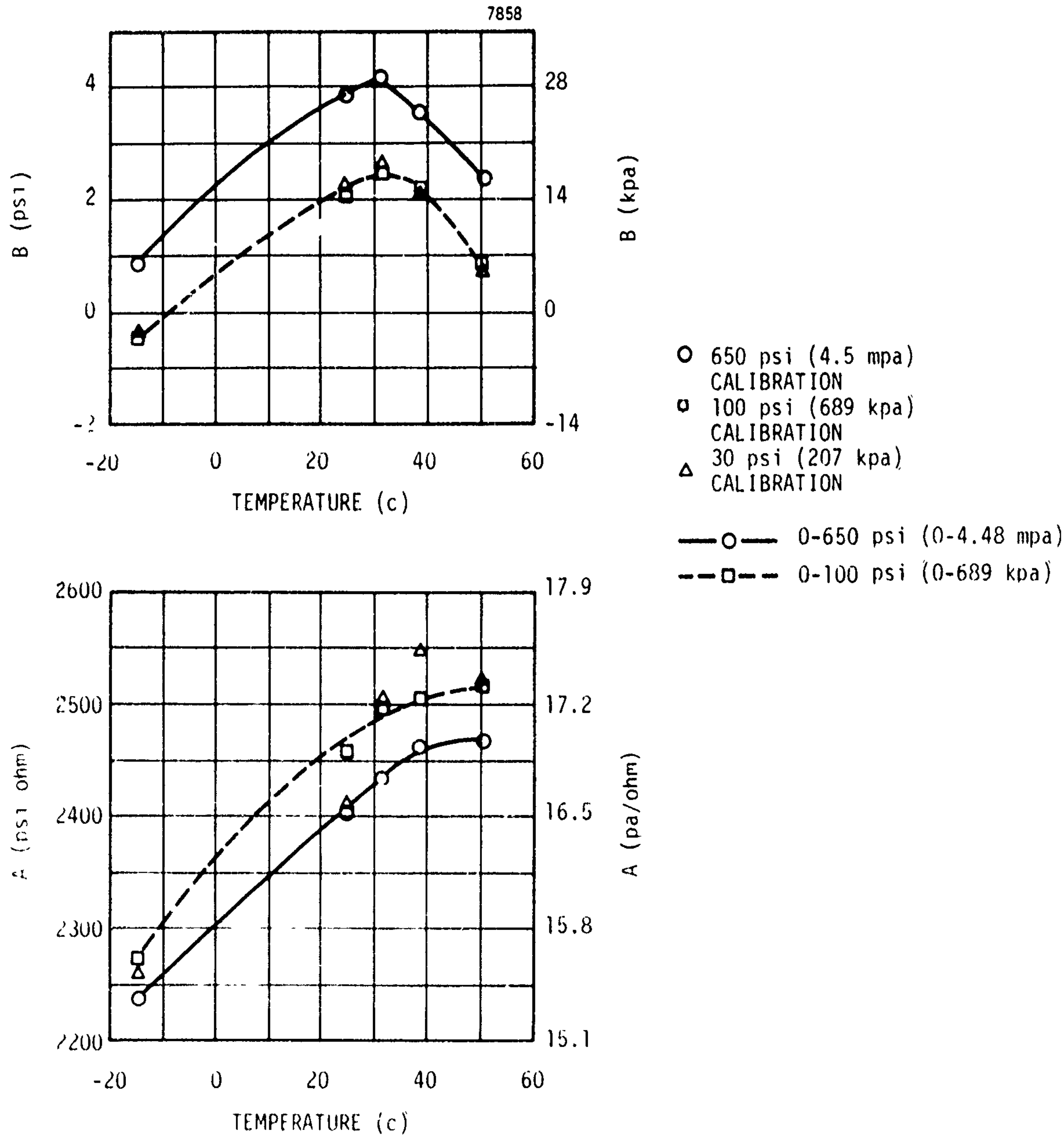

(U) Figure 10 - Least-Squares Fitting Coefficients as a Function of Temperature for the FOXBORO #1 Gage

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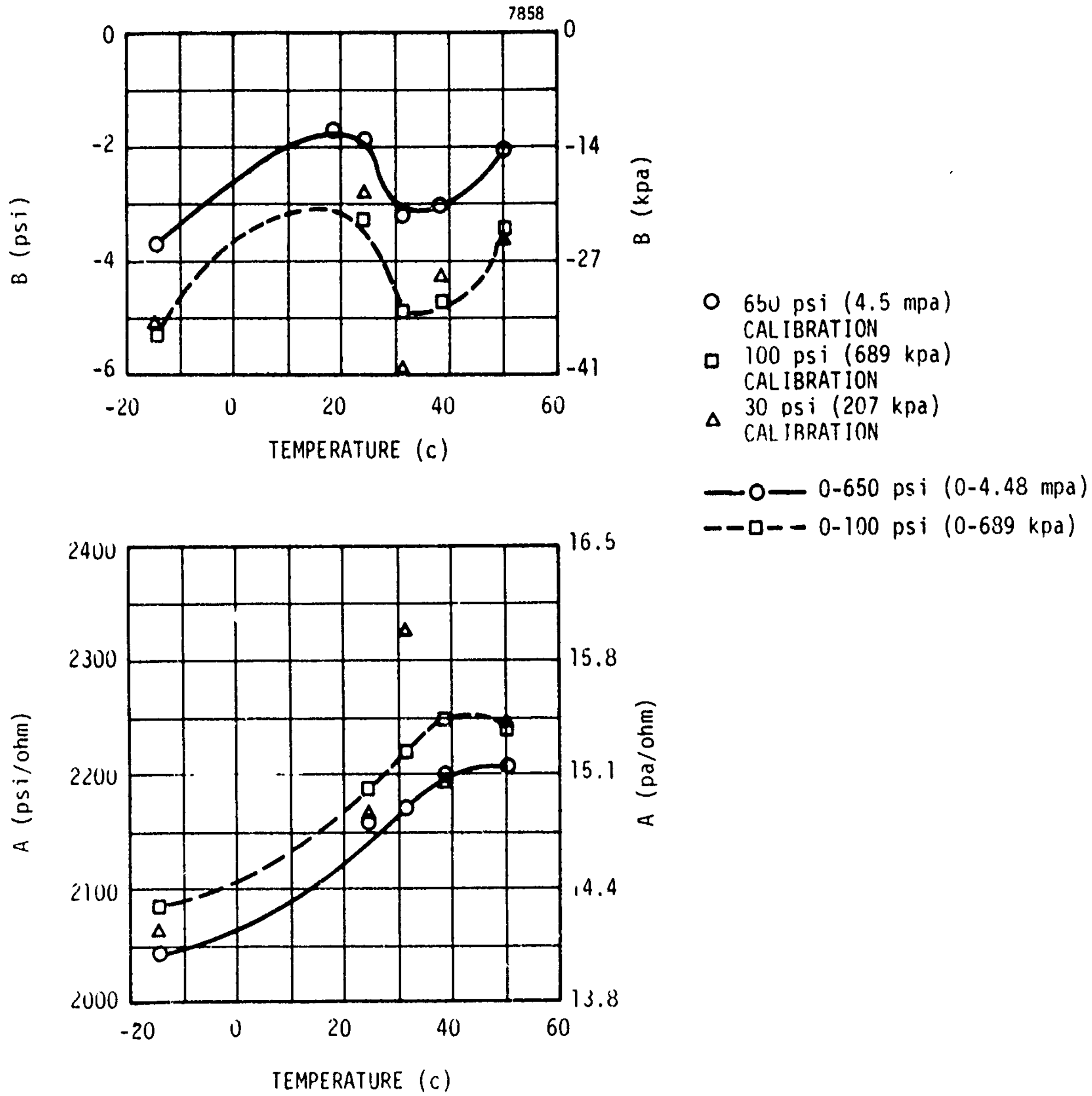

(U) Figure 11 - Least-Squares Fitting Coefficients as a Function of Temperature for the FOXBORO #2 Gage

It should be mentioned that several of the gages incorporate temperature compensation circuitry. These gages are generally strain-gage type transducers. Potentiometric type gages include mechanical linkage arrangements designed for temperature compensation.

Comparing the effect of temperature on the coefficients of the least-squares fitted line for the four strain-gage type transducers (i.e. BELL & HOWELL, SENSOTEC AND FOXBORO #1 AND #2), it appears that for three gages there is a general trend for sensitivities to increase with increasing temperatures. This does not hold true for the BELL & HOWELL gage, however, Further, the sensitivity changes for calibrations over different pressure ranges. There does not appear to be any correlation between gages concerning the zero pressure (y-axis intercept). In some cases, the function increases monotonically with temperature, while for other gages, there are several inflection points. It should be remembered that the temperature effects on the two FOXBORO gages may be decreased with the addition of temperature compensation circuitry. Depending on the operational temperature range expected, it may be necessary to correct the fitting coefficients to avoid errors on the order of several feet.

Figures 12 and 13 allow a direct comparison of data for the different gages. In the upper graphs, the difference between the zero-shift at each temperature and the zero-shift at room temperature, which was 75 degrees Fahrenheit (24 degrees Celsius), are shown (i.e. B other temperature - B room temperature). The lower graphs show the ratio of the gage sensitivity at the temperature of interest to the gage sensitivity at room temperature.

A comparison of the effects of temperature on the coefficients between gages is best seen in Figures 12 and 13. It appears that for the 0 to 650 psi (0-4.5 mpa) calibration, the sensitivities of the CONRAC and SENSOTEC gages are least affected by temperature, but for the 0 to 30 psi (0-206 kPa) calibration, the CONRAC performance is also degraded. The effect of temperature on the zero-voltage pressure is strongly a function of the temperature range of interest. For example, in Figure 13 if one is not concerned with low temperatures, the SPARTON SOUTHWEST gage coefficient "B" is least affected by temperature but is the worst at low temperatures. In Figures 12 and 13, it was decided not to connect the data points as many curves would cross each other, thereby detracting from the clarity of the information presented.

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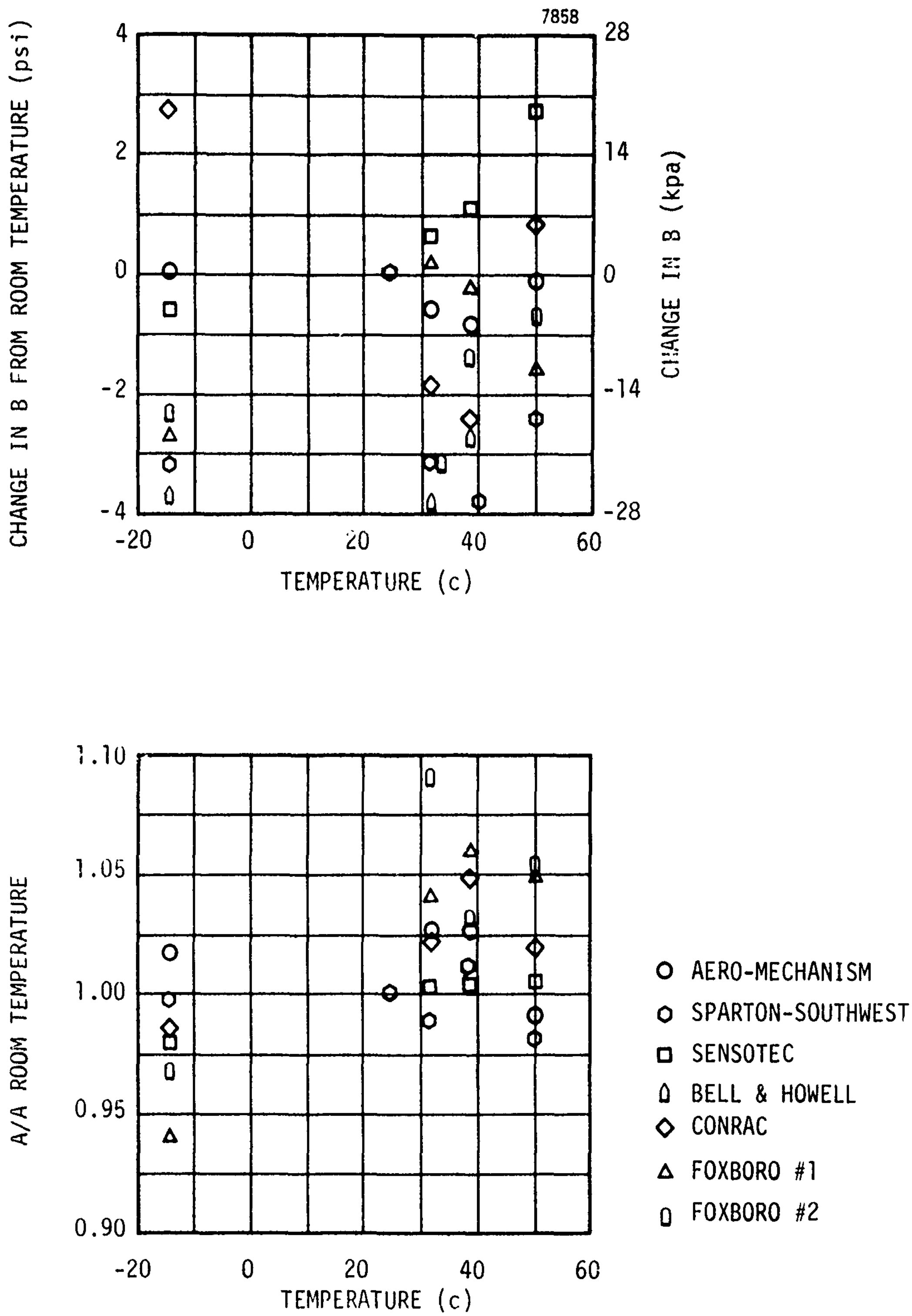

(U) Figure 12 - Change in Fitting Coefficients for All Gages Based on Room Temperature Values for a 0-30 psi (0-207 kPa) Calibration

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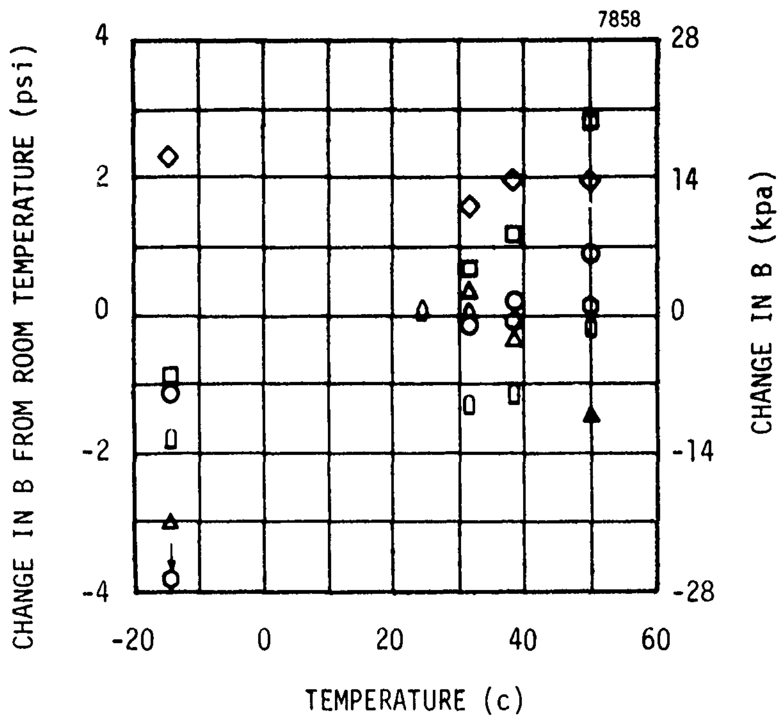
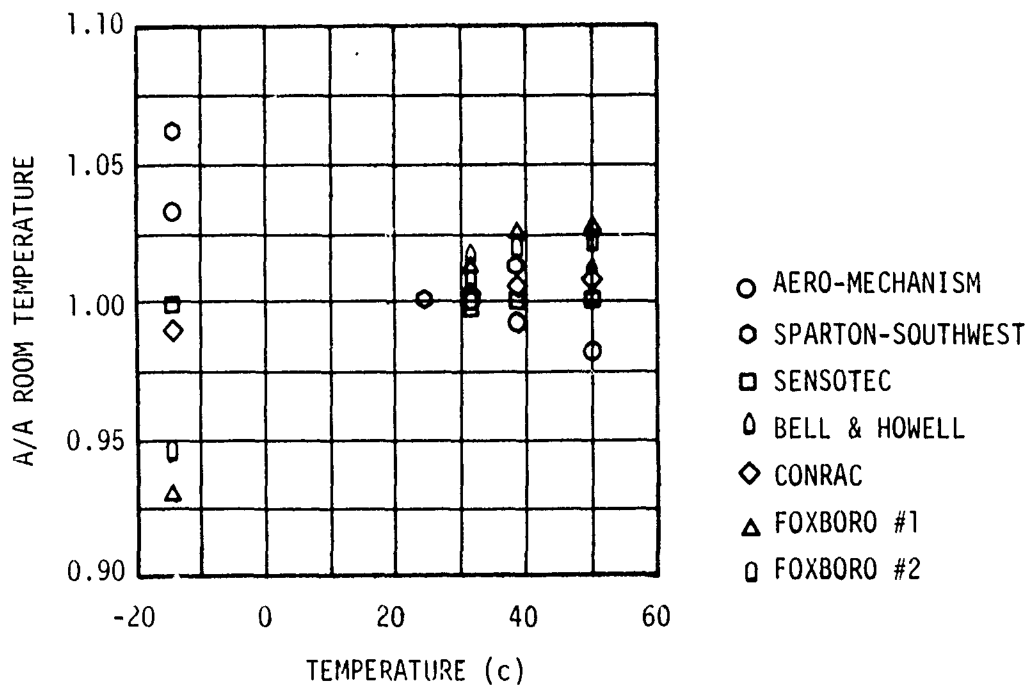




(U) Figure 13 - Change in Fitting Coefficients for All Gages Based on Room Temperature Values for a 0-650 psi (0-4.5 MPa) Calibration

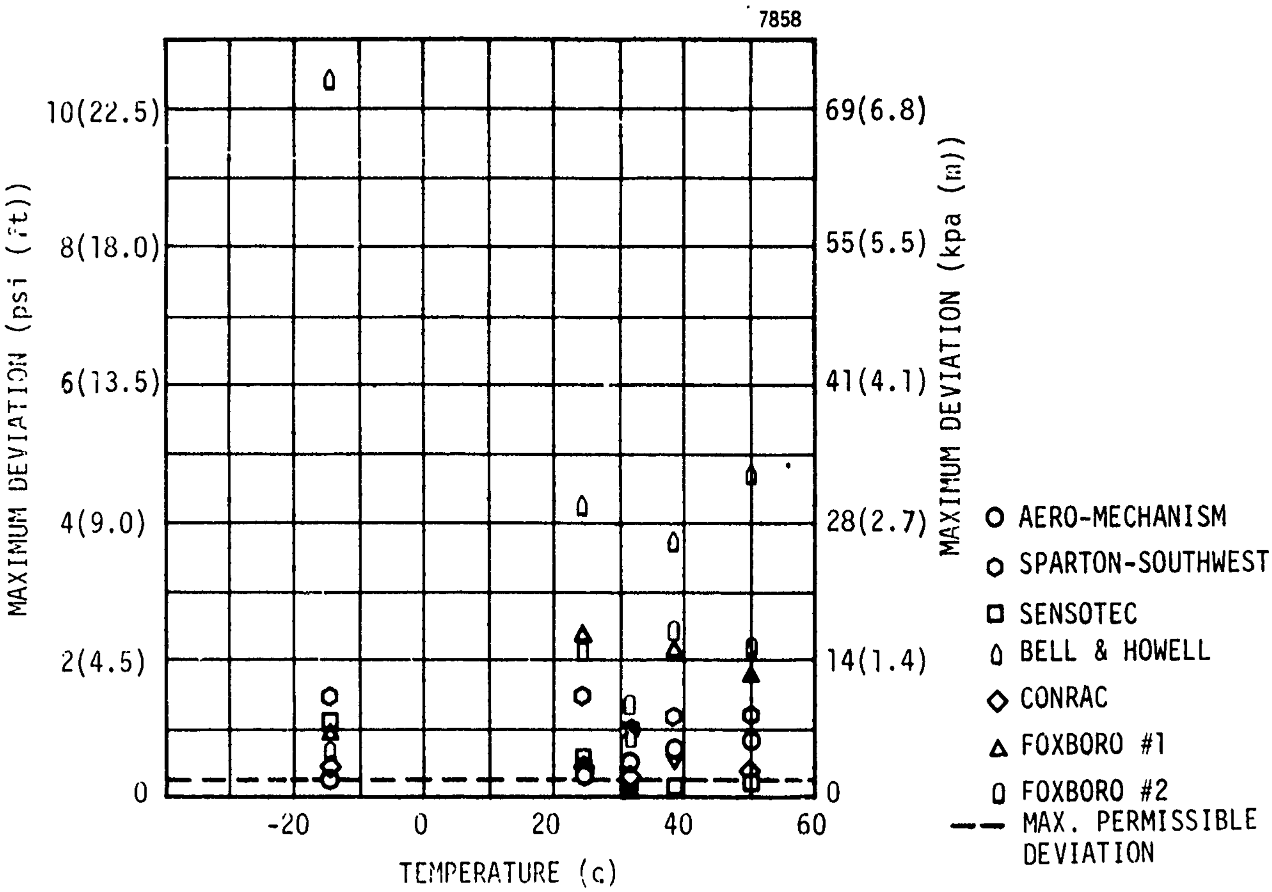
Figures 14 and 15 show maximum deviations of measured data from the fitted line as functions of temperature for all gages, while Figures 6 and 7 present the maximum deviations expressed as a percentage of each gage's maximum operating pressure for the temperature range.

The effect of temperature on the maximum deviations is presented in Figures 14 to 17. The required depth accuracies are ± 7 in. or 0.26 psi (± 17.8 cm or 1.79 kPa) from 0-50 ft or 0-22 psi (0-15 m or 0-151 kPa) and ± 20 ft or 8.86 psi (± 6.1 m or 61 kPa) from 0-1467 ft or 0-650 psi (0-44 m or 0-4.48 MPa). Since a given error in psi can represent a different percentage of various gages' maximum operating pressures, both the deviation in psi and feet and the deviation as a percentage are shown. Based on Figure 15, the only gages that meet the deep-depth requirement for the entire temperature range are AERO-MECHANISM, SENSOTEC, and CONRAC. Both the SENSOTEC and the CONRAC gages are accurate to within ± 4.5 ft (1.4 m) for the entire temperature range, or 0.15 percent of full scale. If the area of interest does not include extremely cold temperatures (0 degree Celsius), the CONRAC gage is accurate to ± 1.8 ft (0.54 m) or 0.15 percent and the SENSOTEC gage is accurate to ± 1.35 ft (0.41 m) or 0.075 percent.

Figure 14 shows the maximum deviation in psi as a function of temperature for a 0 to 30 psi (0-207 kPa) calibration. It should be mentioned that the same gage was used for both deep- and shallow-depth calibrations. However, in actual applications, two gages are often used, with the shallow-depth gage having a much lower sensitivity (i.e. smaller coefficient "A") than the deep-depth gage. Since it was not feasible either economically or logistically to purchase both gages, it may be assumed for most gages that the percentage of full-scale accuracy would be the same for both low- and high-pressure gages. Thus, a 650 psi (4.5 MPa) gage calibrated from 0 to 650 psig (0-4.5 MPa) with a 0.2 percent accuracy would correspond to a 50 psig (344 kPa) gage with a 0.2 percent accuracy or 0.10 psi (6.9 kPa), which is well within the shallow-depth accuracy requirement.

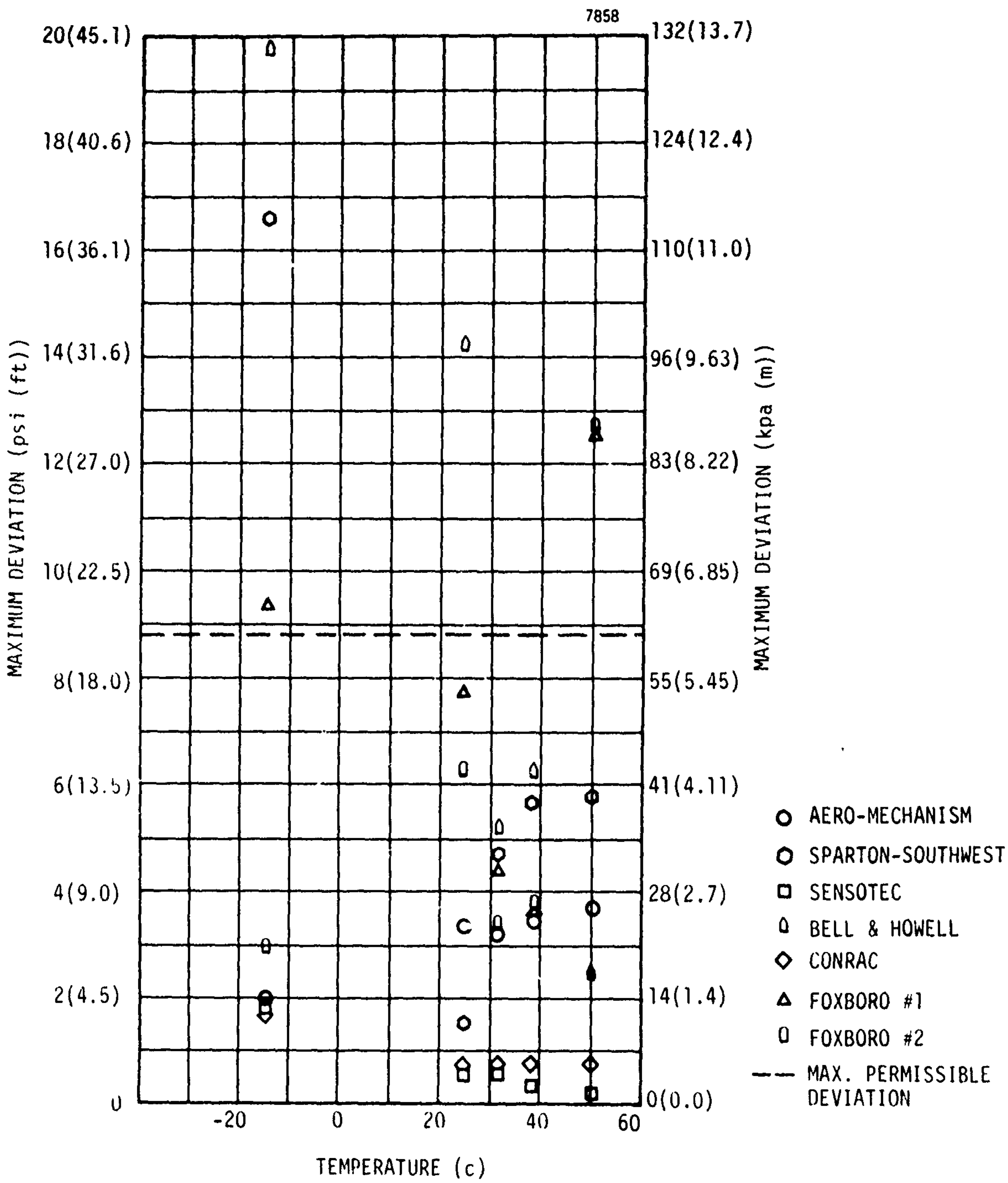
Low-pressure calibrations are more susceptible to voltage fluctuations, friction, weight inaccuracies, etc., since these represent a larger percentage of the input parameters than they would for a high-pressure calibration. Therefore, the output is likely to be "noisier".

(UNCLASSIFIED)



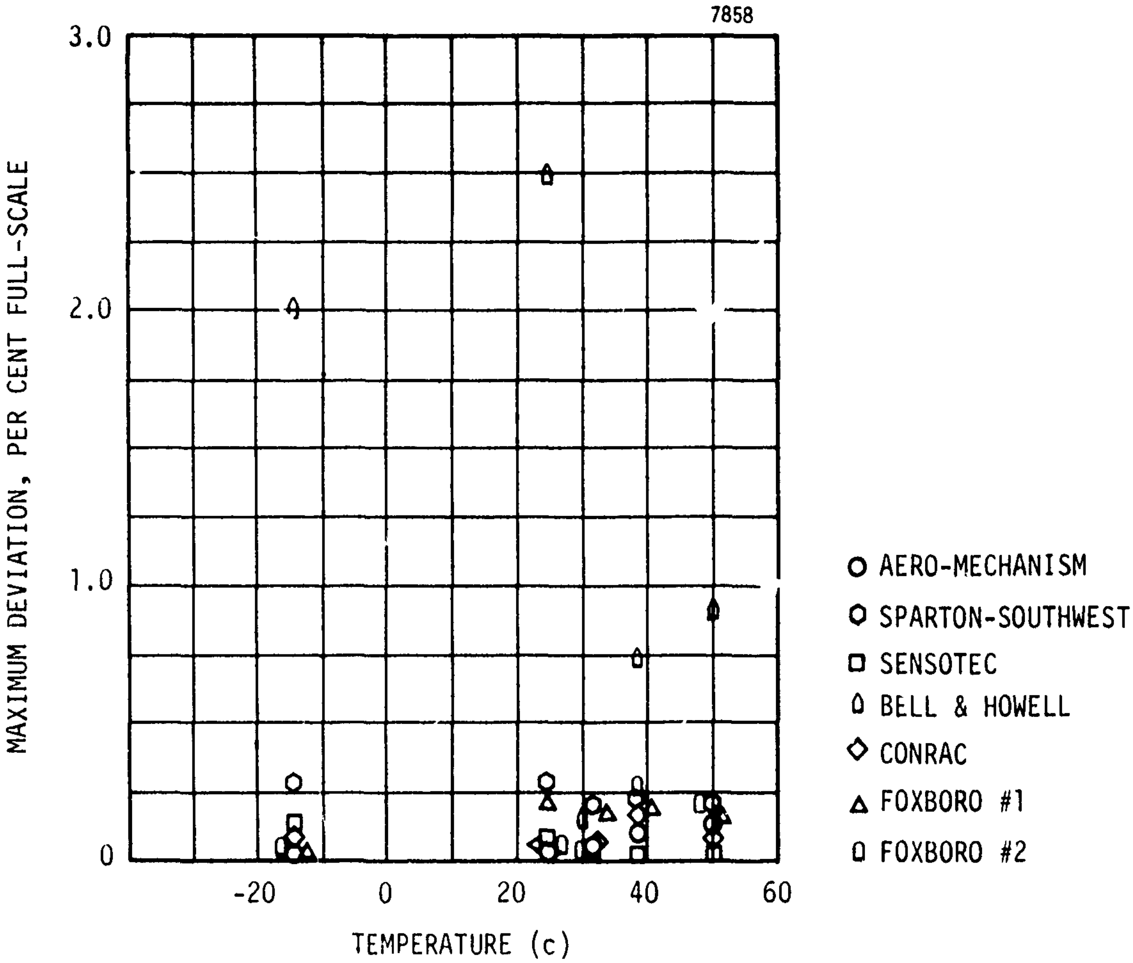
(U) Figure 14 - Maximum Deviation as a Function of Temperature for All Gages for a 0-30 psi (0-207 kPa) Calibration

(UNCLASSIFIED)



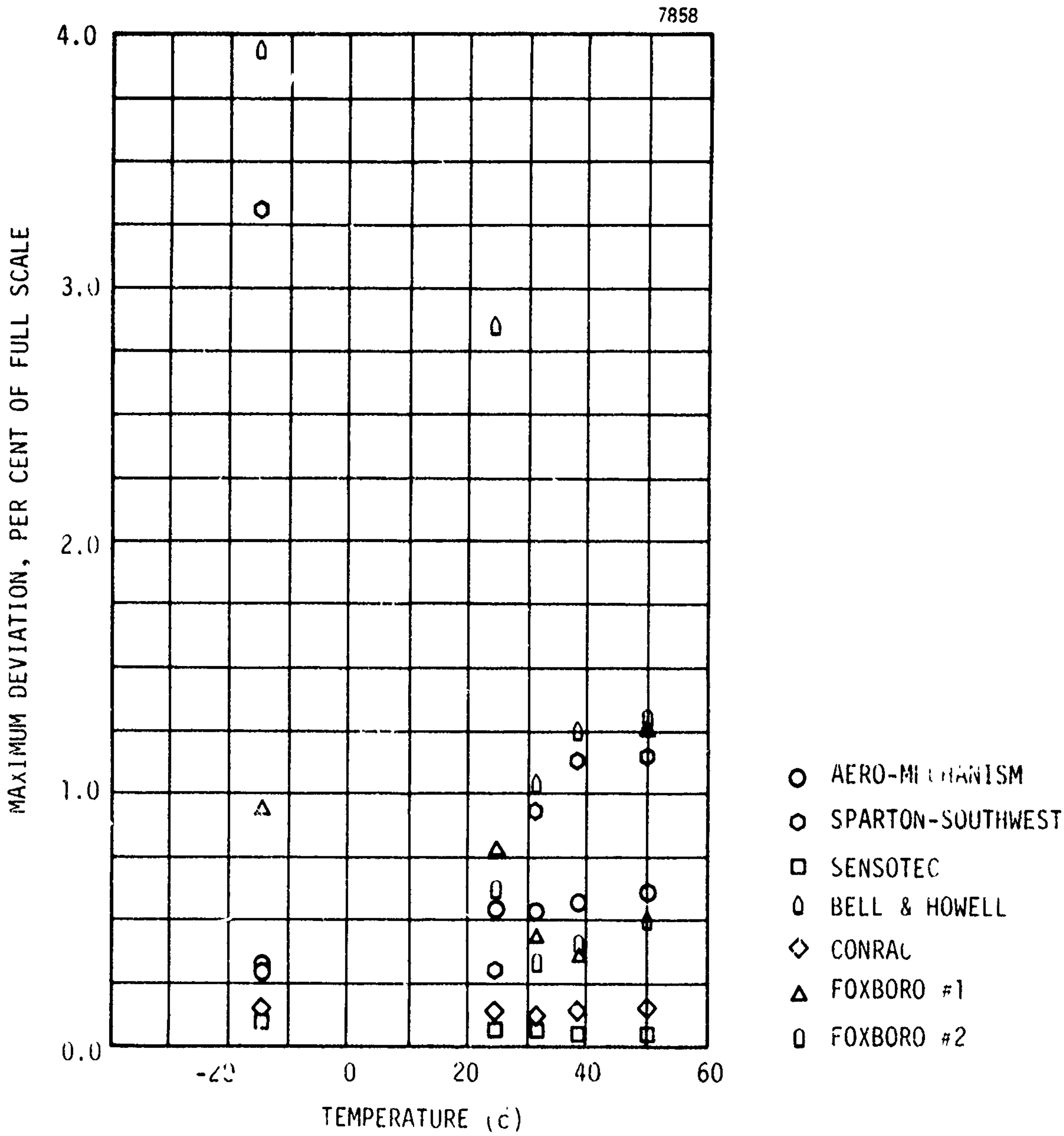
(U) Figure 15 - Maximum Deviation as a Function of Temperature for All Gages for a 0-650 psi (0-4.5 MPa) Calibration

(UNCLASSIFIED)



(U) Figure 16 - Maximum Deviation as a Percentage of Transducer Full-Scale Range as a Function of Temperature for a 0-30 psi (0-207 kPa) Calibration

(UNCLASSIFIED)



(U) Figure 17 - Maximum Deviation as a Percentage of Transducer Full-Scale Range as a Function of Temperature for a 0-650 psi (0-4.5 MPa) Calibration

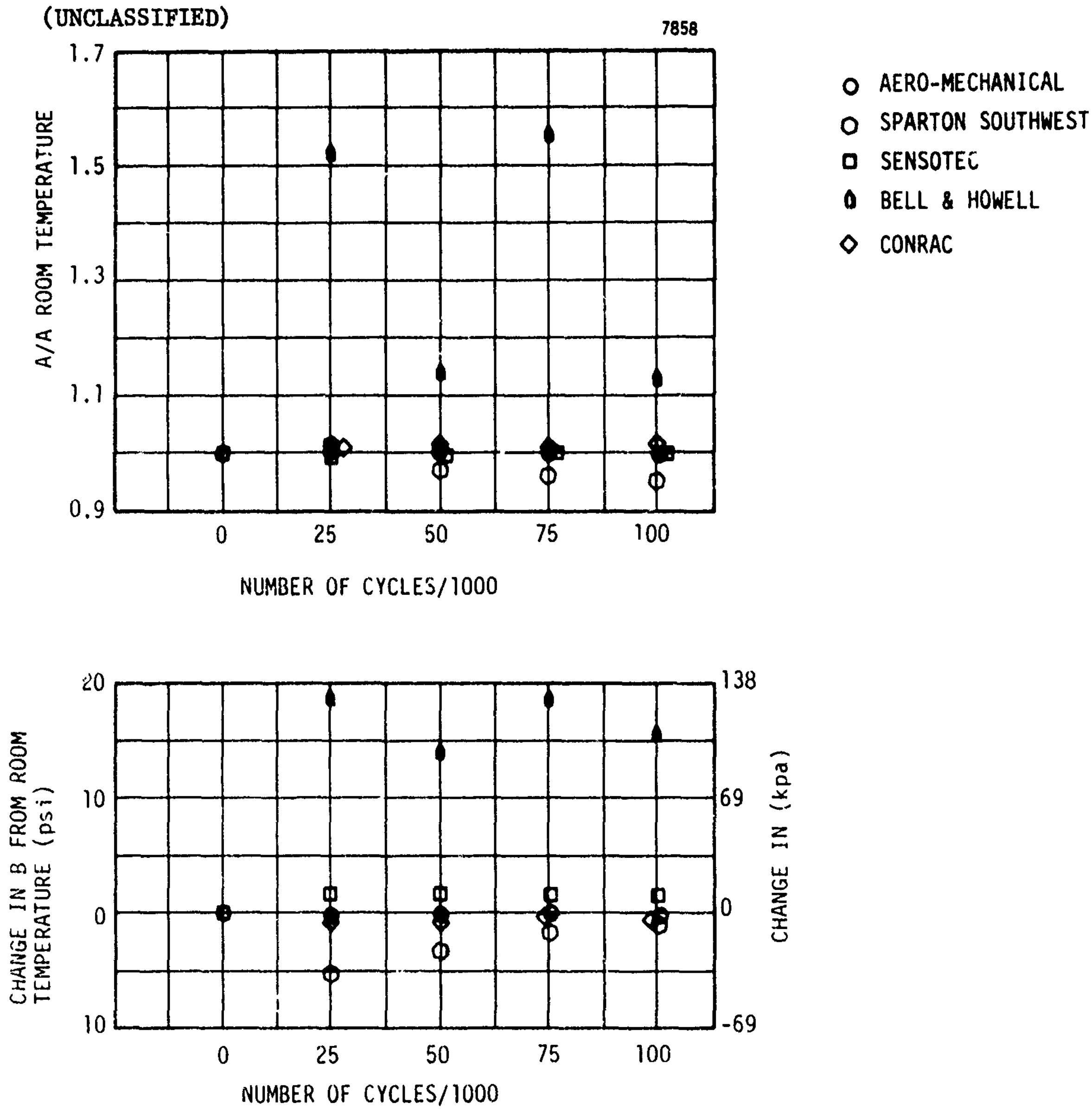
From Figures 14 and 16 the AERO-MECHANISM, CONRAC and SENSOTEC gages are within ± 1 psi (7 kPa) for the entire temperature range. This corresponds to 0.1, 0.2 and 0.13 percent, respectively. If 50 psig (344 kPa) gages were used, the resulting accuracies based on the same percentages would be 0.05, 0.1 and 0.065 psig (344, 689 and 448 pa) or 1.35 in., 2.70 in. and 1.76 in. (3.43 cm, 6.85 cm and 4.47 cm), respectively.

EFFECTS OF SIMULATED LONG-TERM CYCLING

The results of the cycling investigation are presented in this section and Tables 6 and 7 in Appendix A. They are based on the complete calibrations performed at the end of each week of cycling. All cycling occurred at 24 degrees Celsius ± 2 degrees. The baseline values for gage performance are derived from the four complete calibrations at room temperature (24 degrees Celsius) performed prior to beginning the long-term cycling. The analysis is shown for two pressure ranges: 0-30 psig (0-207 kPa) and 0-650 psi (0-4.5 MPa).

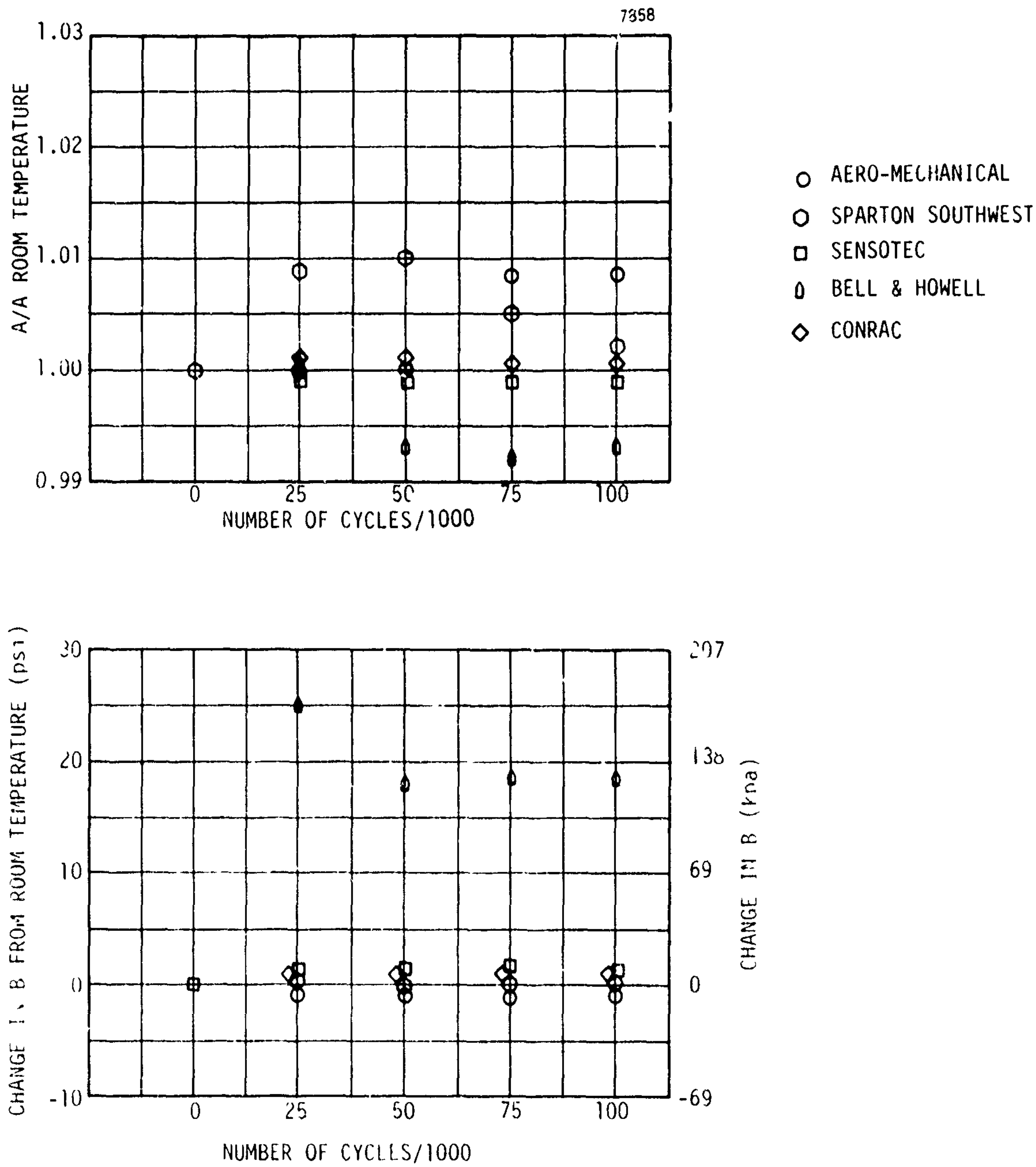
Figures 18 to 20 show the effect of cycling on the least-squares fitting coefficients. The upper graphs present nondimensionalized sensitivities for each gage, while the lower graphs present the shift in zero-offset from the room temperature value. Based on the 0-30 psi (0-207 kPa) calibration in Figure 18, the AERO-MECHANISM gage is least affected by cycling, followed by SENSOTEC and CONRAC gages. The change in sensitivity for these three gages is less than one percent, while the maximum change in the y-intercept is less than 2 psi (14 kPa). Shifts in the coefficients for the BELL & HOWELL and SPARTON-SOUTHWEST gages are as great as 60 percent and 35 psi (240 kPa) for the sensitivity and zero-shift, respectively. Figure 19 shows the same quantities for a 0 to 650 psi (0 to 4.5 MPa) calibration. The sensitivity for the AERO-MECHANISM gage shifted by one percent, while the CONRAC and SENSOTEC gage sensitivities shifted less than 0.1 percent. From Figure 20, the FOXBORO gage coefficients shifted as much as 500 percent and 200 psi (1.4 MPa) for the sensitivity and zero-shift, respectively.

Figures 21 to 23 show the effect of cycling on the maximum deviation of data form the fitted line. All gages but SPARTON-SOUTHWEST showed no increase in the maximum deviation as a function of the number of cycles. In fact, several gages actually show an increase in overall accuracy. The only explanation that can be offered at this time is that some gages require a certain "working-in" period to eliminate any mechanical "memory" and to reach a steady-state condition.

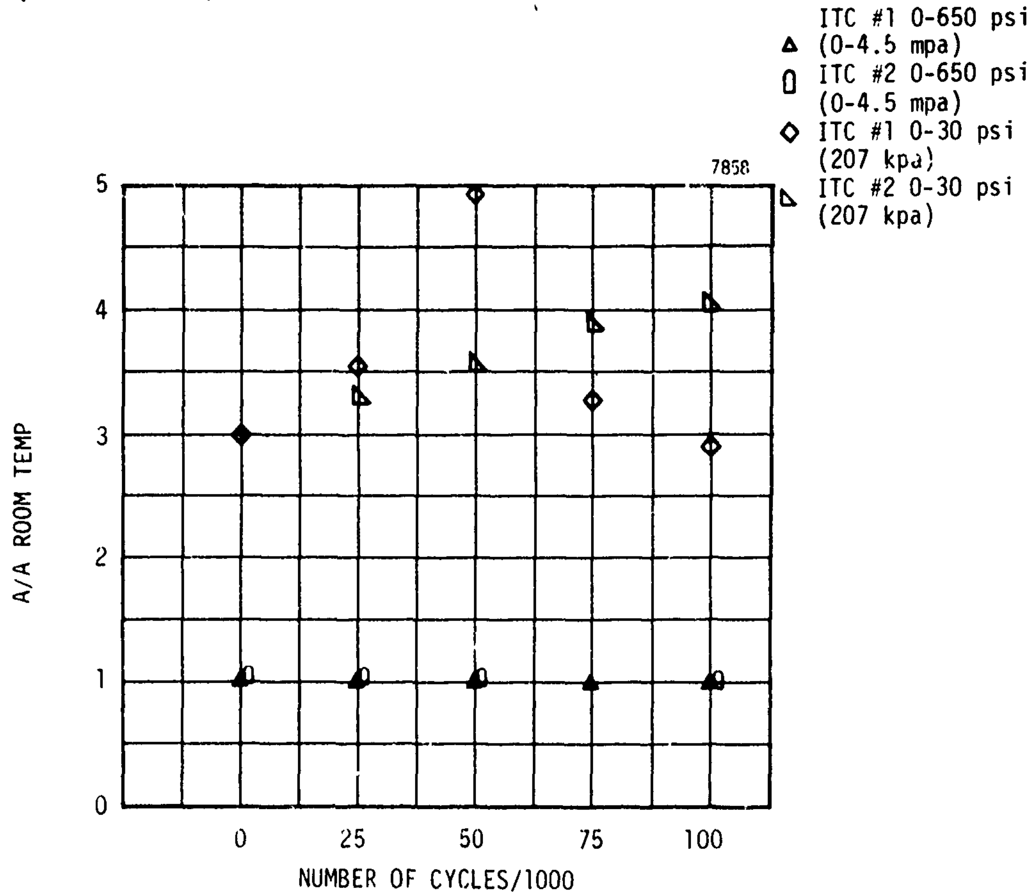


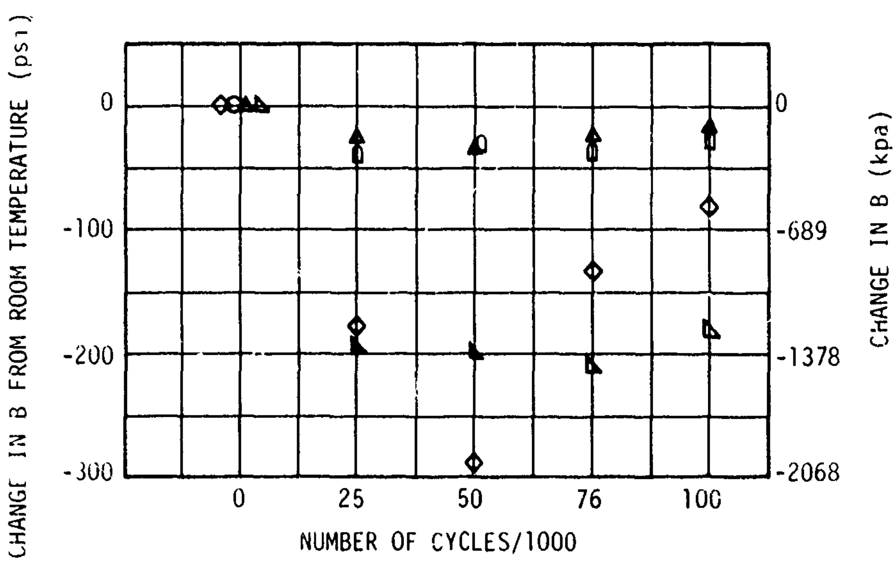
(U) Figure 18 - Change in Fitting Coefficients as a Function of Total Cycles for a 0-30 psi (0-207 kPa) Calibration

(UNCLASSIFIED)

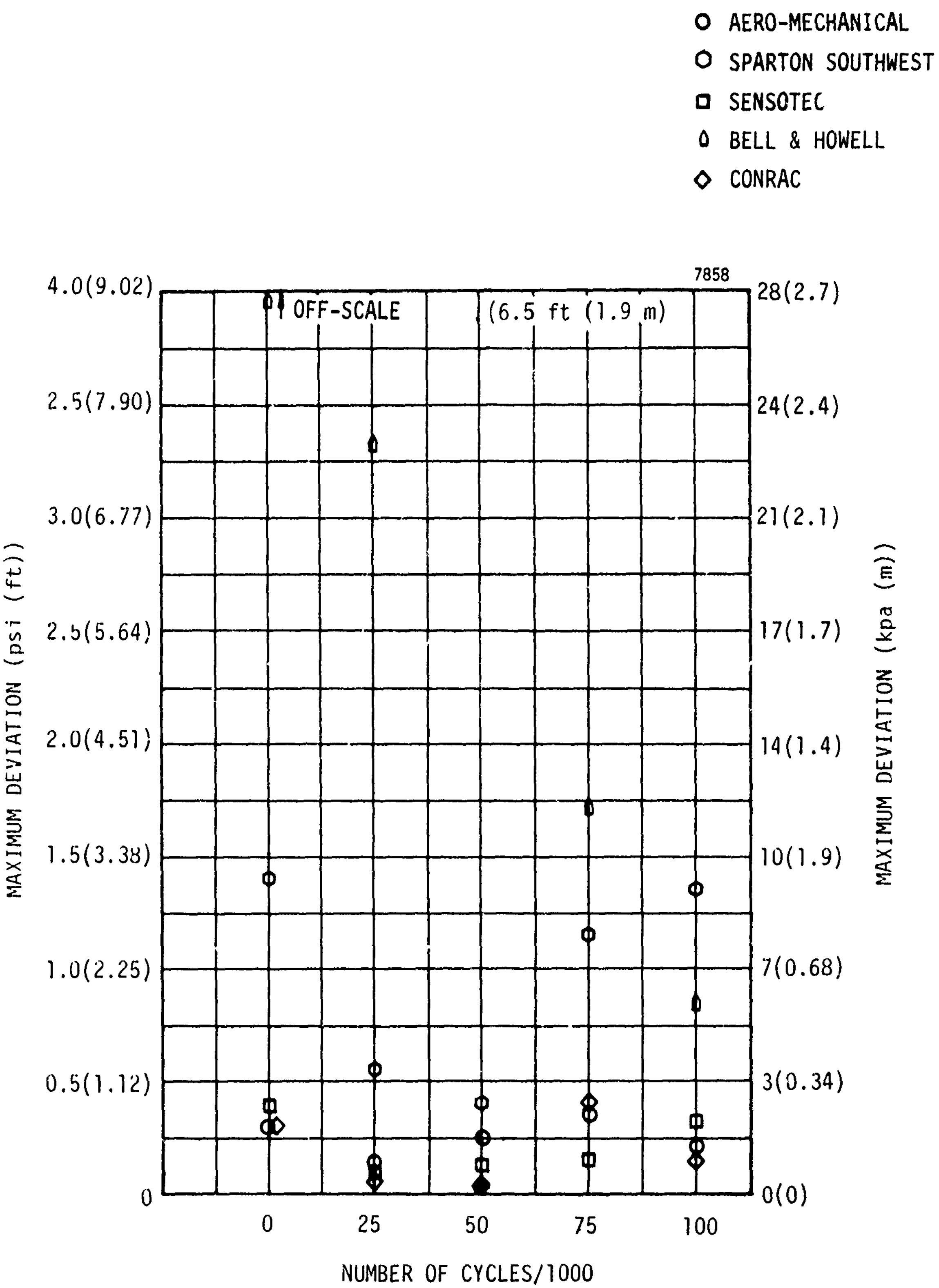


(U) Figure 19 - Change in Fitting Coefficients as a Function of Total Cycles for a 0-650 psi (0-4.5 MPa) Calibration



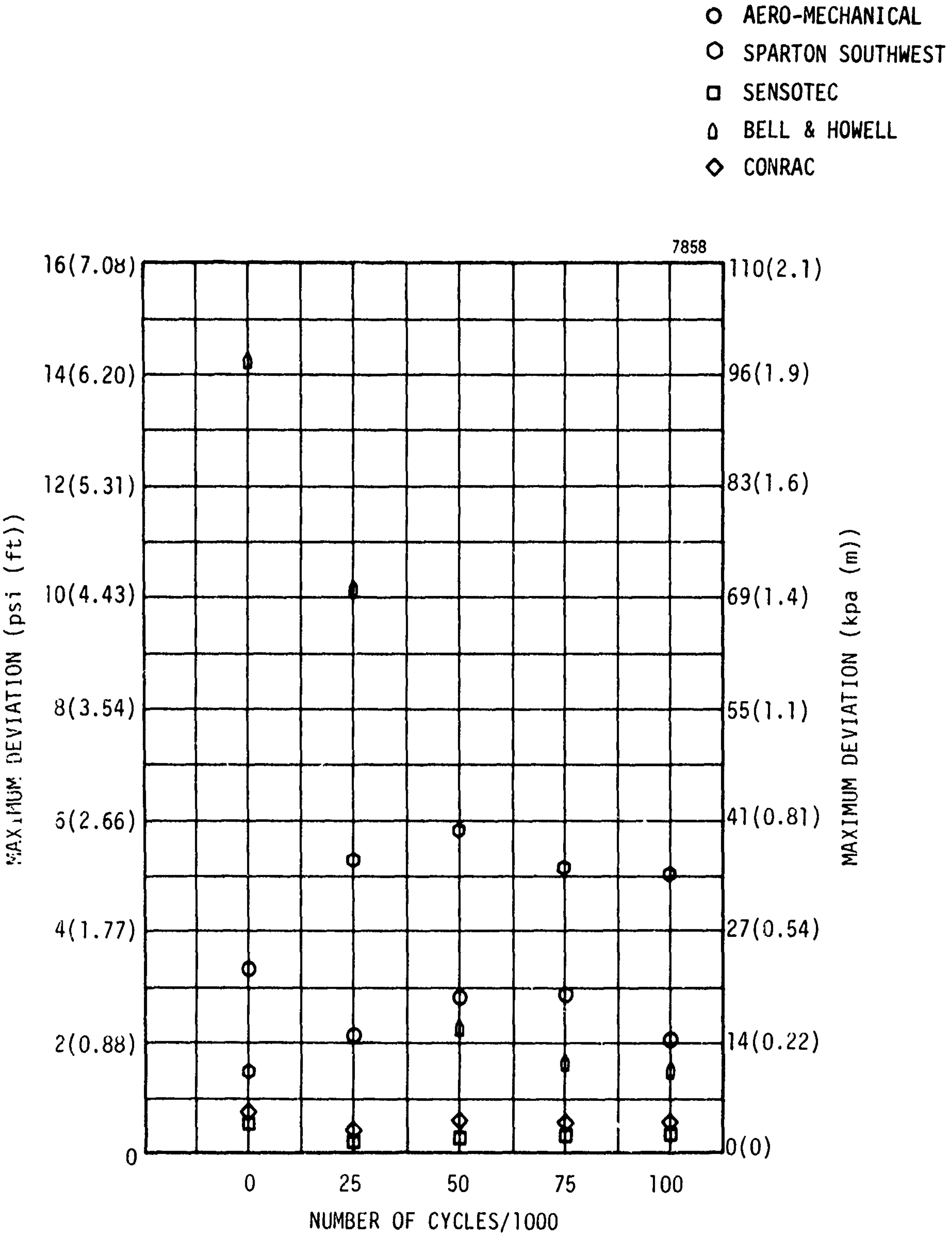


(U) Figure 20 - Change in Fitting Coefficients as a Function of Total Cycles for the FOXBORO Gages



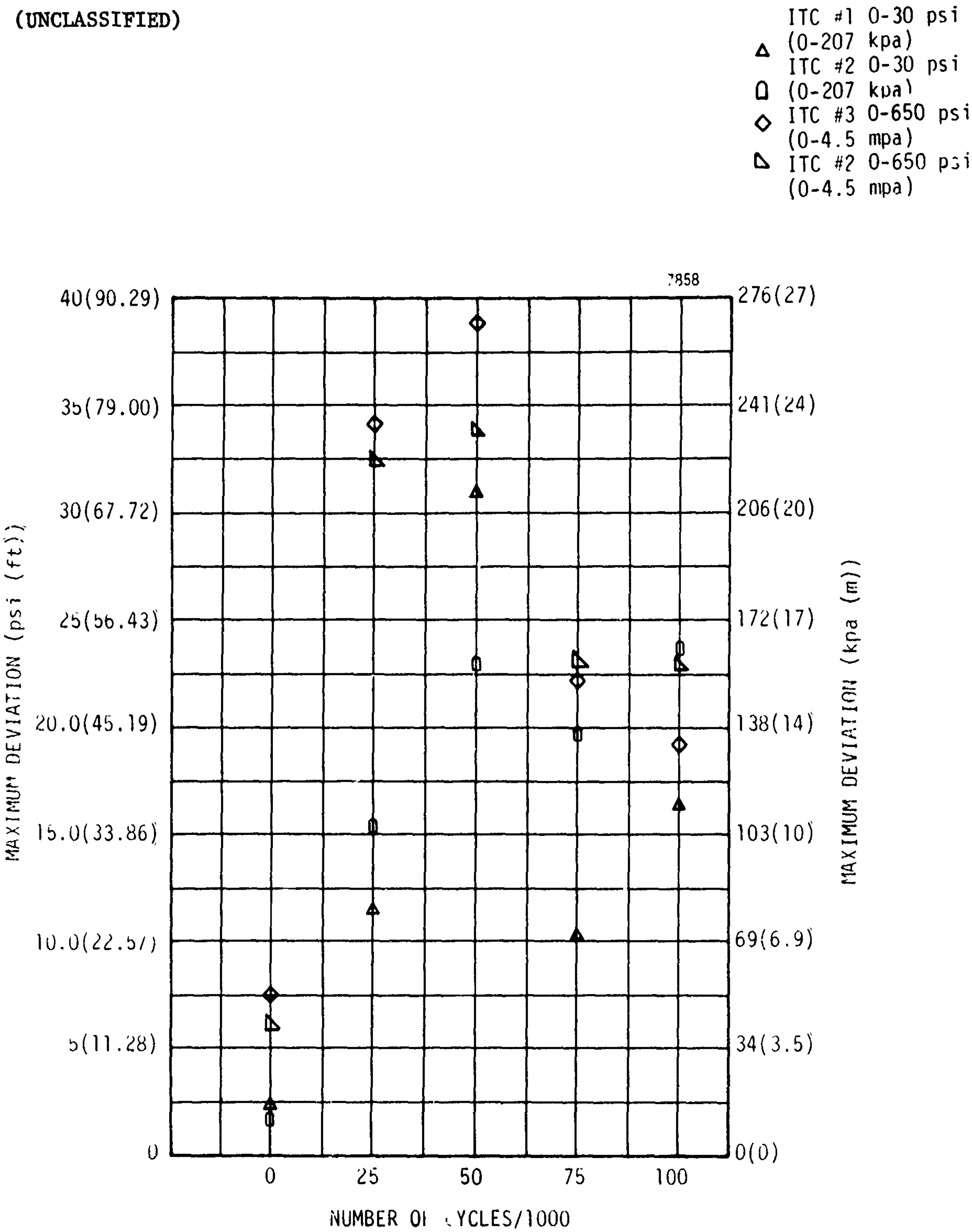
(U) Figure 21 - Maximum Deviation as a Function of Total Cycles for a 0-30 psi (0-207 kPa) Calibration

(UNCLASSIFIED)



(U) Figure 22 - Maximum Deviation as a Function of Total Cycles for a 0-650 psi (0-4.5 MPa) Calibration

(UNCLASSIFIED)



(U) Figure 23 - **Maximum Deviation as a Function of Total Cycles for the FOXBORO Gages**

Figure 23 shows the effect of cycling on maximum deviation for the FOXBORO gages. In both calibration ranges, the accuracies substantially deteriorate with cycling, but the relationship is not monotonic (i.e. the maximum deviations do not occur after the maximum number of cycles). The causes for this marked deterioration in the FOXBORO gage performance are seen in Figures 24a and 24b. The gages become highly nonlinear below 100 psi (690 kPa), resulting in large errors when fitted with a straight line. Figure 24a shows that the sensitivity for the 0-650 psi (0-4.5 MPa) calibration is almost identical to the original precycling sensitivity. The large errors occur in the lower pressure range.

A SURVEY OF OVERPRESSURE PROTECTION DEVICES

Figure 25 shows the AERO-MECHANISM Overpressure Protection device. The deep-depth gage, shallow-depth gage and blanking valve (protection device) are all mounted together as a single unit, with the blanking valve between the two depth gages. The operation of the valve is described below.

Ambient water enters the valve through the inlet port 11. The water passes through channels in the base and fills the interior of the valve assembly (excluding the bellows 5), passing into the shallow-depth gage through the inlet port 10. The water also applies pressure to the baseplate 7 of the bellows, tending to compress the bellows. The adjustment screw 2 and pretensioning spring 9 can be adjusted to vary the spring constant of the bellows assembly. As the pressure increases, the bellows continue to compress. Piece 6 is a disc-shaped plate with an "O-ring" and is connected to the bottom of the bellows. When the bellows are compressed sufficiently (when the desired closing pressure is reached), the plate 6 seats against the bottom of the valve housing, preventing any further flow or increase of pressure in the valve and shallow-depth gage. Since part 6 is actually threaded onto a threaded rod attached to the bellows 5, the distance required for the bellows to compress, and thus the closing pressure, can be varied before the "O-ring" surface seats.

The main advantages of this device are its adjustability and low friction characteristics, allowing closing pressures to be extremely accurate. The main disadvantages are the mechanism's complexity and estimated high cost of fabrication. (The manufacturer would not reveal this cost.)

Details of the second device are shown in Figure 26. The mechanism uses a cylinder/piston arrangement with sliding "O-rings" to maintain the required fluid

(U) Figure 24 - Pressure as a Function of Voltage for the FOXBORO #2 Gage at the Completion of Long-Term Cycling

(UNCLASSIFIED)

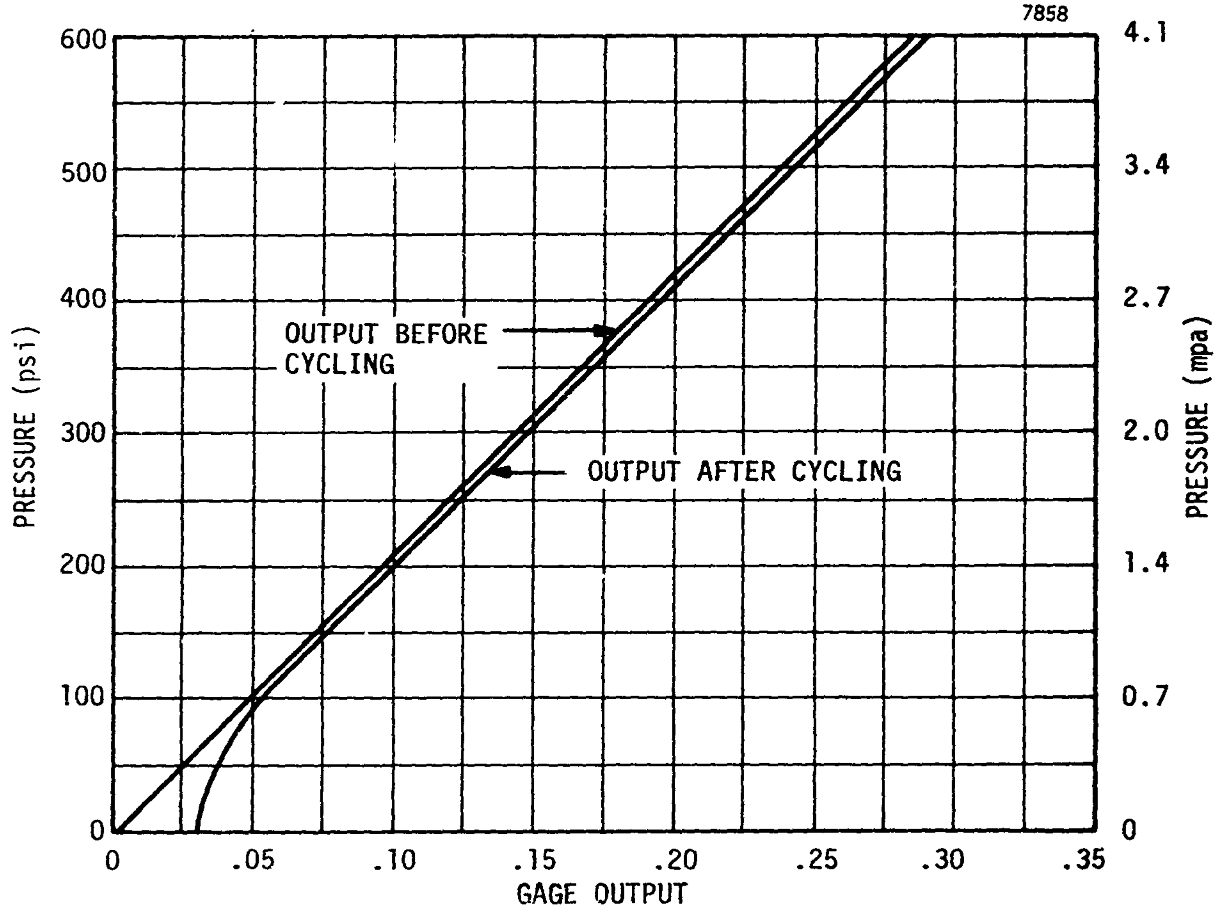
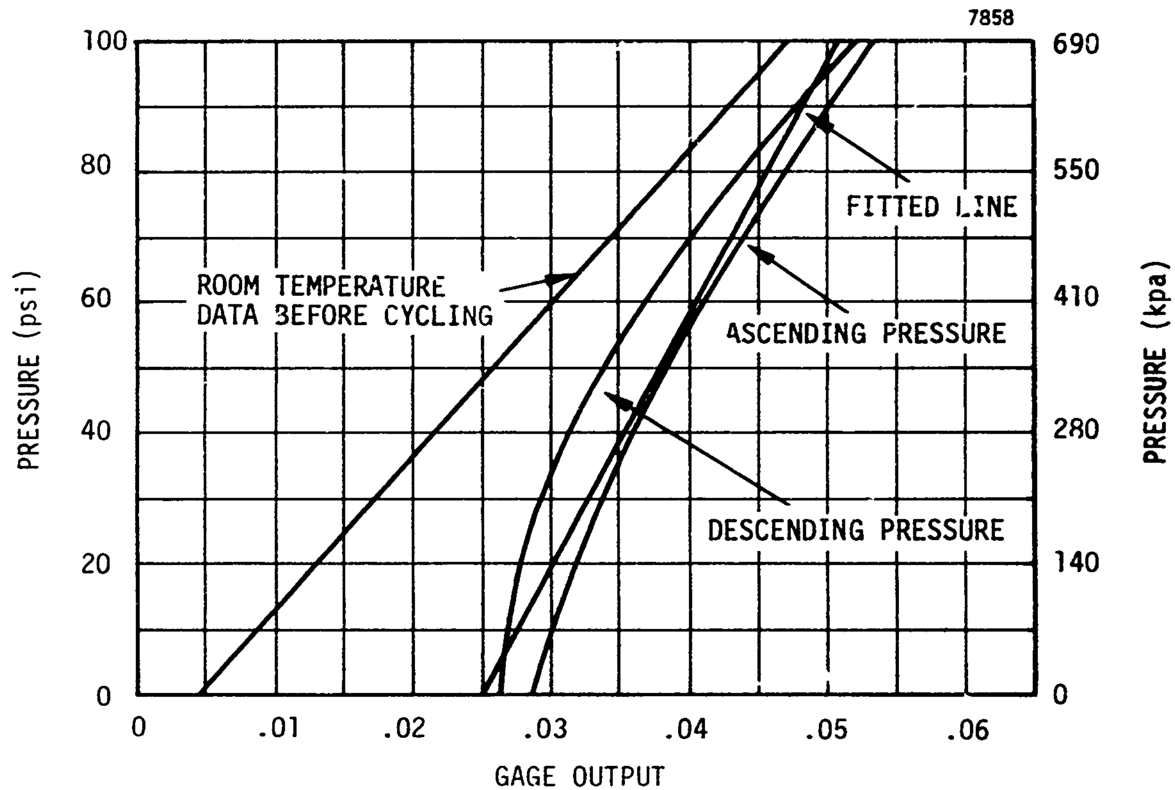


Figure 24a - Gage Output Over a 0-600 psi (0-4.1 MPa) Range

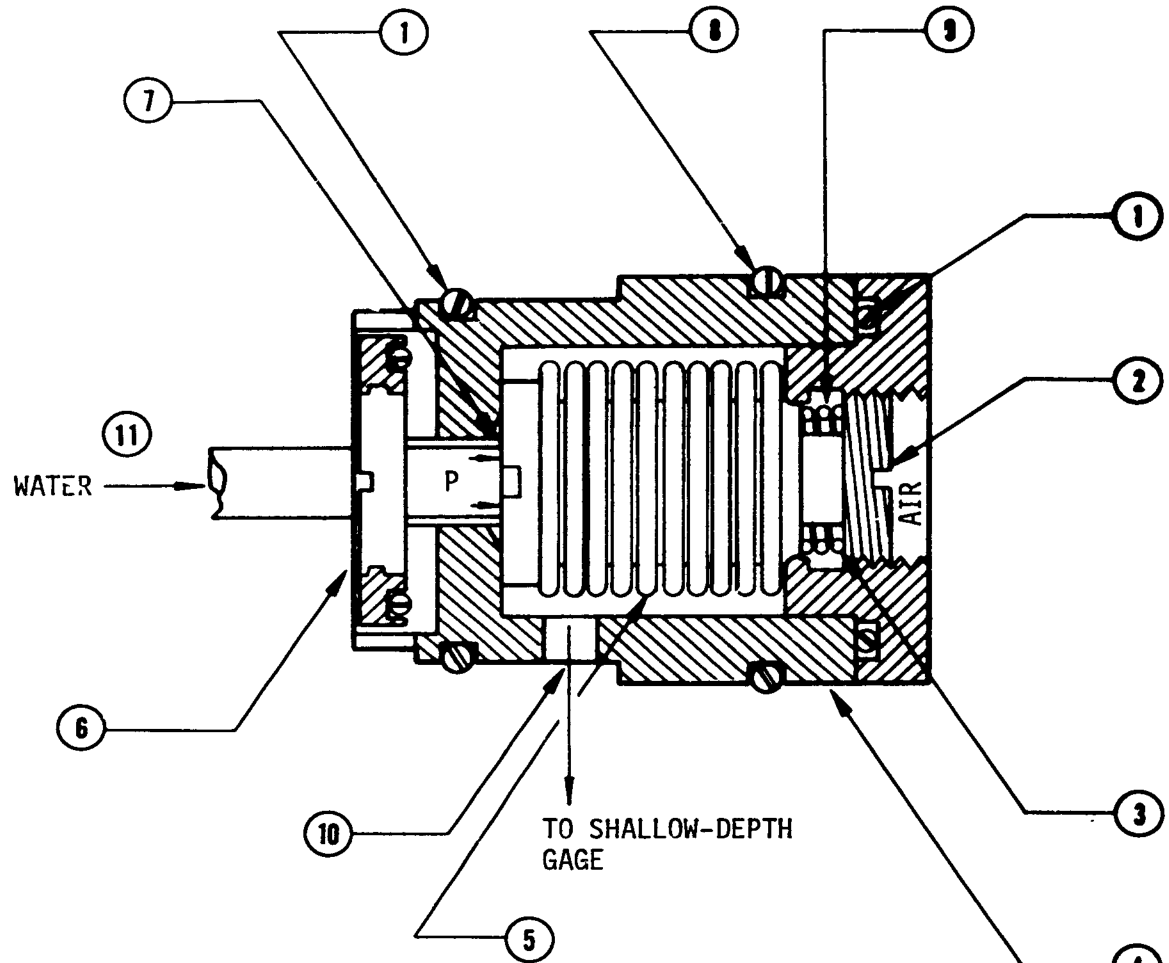
Figure 24. (Continued)

(UNCLASSIFIED)



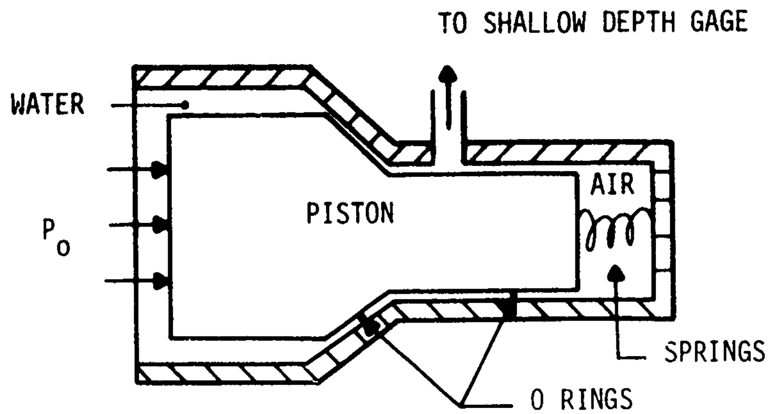
(U) Figure 24b - Gage Output Over a 0-100 psi (0-689 kPa) Range

(UNCLASSIFIED)



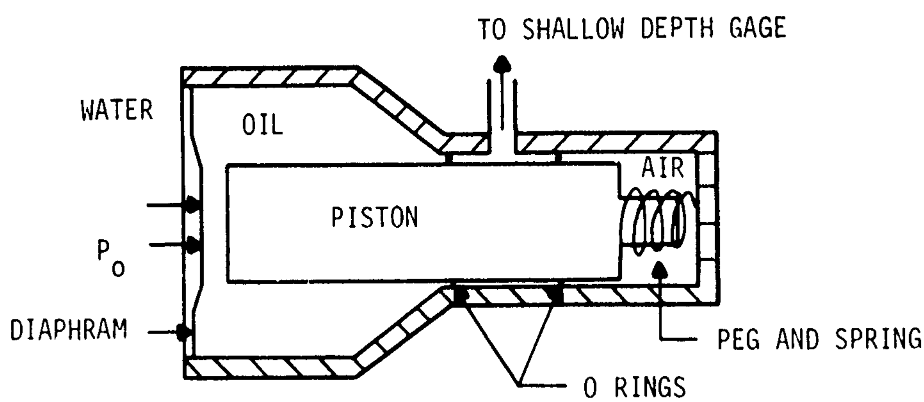
(U) Figure 25 - AERO-MECHANISM Overpressure Protection Device

(UNCLASSIFIED)



(U) Figure 26a - Original Blanking Valve

(UNCLASSIFIED)



(U) Figure 26b - Redesigned Blanking Valve

Figure 26 - Alternate Blanking Valve

seals. Initially the spring is fully extended and water flows past the first "O-ring" and into the shallow-depth gage. As pressure increases, the piston slides back and the forward "O-ring" seats on the level, stopping all further flow. The device shown in Figure 26a did not function properly, however, since the "O-ring" seated on the level continues to compress as pressure increases and allows the pressure in the shallow-depth gage to increase.

The problem was corrected as shown in Figure 26b. The bevelled piston was eliminated and replaced with a straight cylinder. Then, once the forward "O-ring" seats, no further compression occurs and the pressure in the shallow-depth gage remains constant. Also, a positive stop was added to the cylinders to prevent overtravel, and oil is used in the device to prevent corrosion in the depth gage.

One such device has been fabricated at a cost of $300.00 and some testing has been performed. The device functions properly at the pressures required for submarine communications buoys. However, some problems do exist. The sliding "O-rings" produce very high friction, which may prevent accurate setting of closing pressures as well as requiring periodic replacement of the "O-rings". At present, a new spring is required for each closing pressure. It is believed, however, that a pretensioning screw could be installed to provide some variability with each spring.

The advantages of this device are its simplicity, low cost of fabrication and extremely small size (approximately 1 in. long (25.4 mm) and 0.5 in. (12.7 mm) 12.7 mm) diameter).

DEPTH-GAGE MOUNTING LOCATION ANALYSIS

The geometric analysis of the effect of buoy pitch and roll on the relative positions of two points representing the locations of the depth gage and the point in the buoy to which buoy depth is referenced is presented in Appendix B. The resulting equations are used to determine the errors in antenna floating length and submerged trail distance (the distance between the submarine and the electrical phase center of the antenna).

For a maximum pitch angle of 15 degrees and a maximum roll angle of 2 degrees at a speed of 6 knots and a buoy depth of 8 ft (2.5 m), the calculated floating length error is 23.92 ft (7.29 m) and the submerged trail error is 11.92 ft (3.63 m). Based on a nominal floating length of 97.00 ft (29.56 m) and a nominal submerged trail of 151.01 ft (46.03 m) (Reference 1), this is equivalent to a 24.6 percent error in floating length and a 7.9 percent error in submerged trail.

CONCLUSIONS AND RECOMMENDATIONS

Based on the analysis of the effect of temperature and long-term cycling on depth-transducer accuracy, linearity and repeatability, the following conclusions are drawn:

1. The effects of temperature on gage-performance cannot be neglected, particularly in the shallow-depth range.

2. The behavior of the "fitting" coefficients as a function of temperature is different for each gage and is dependent on the temperature rang of interest.

3. The only gages meeting deep-depth accuracy requirements over the entire temperature range are the AERO-MECHANISM, SENSOTEC AND CONRAC gages.

4. Only the FOXBORO and SPARTON-SOUTHWEST gages exhibit a decrease in accuracy with increased cycling. Several gages exhibit a slightly increased accuracy with increased cycling.

5. The gages least affected by long-term cycling are the AERO-MECHANISM, CONRAC, and SENSOTEC gages.

6. The AERO-MECHANISM device is too large and undependable for long-term operation.

7. Substantial errors in the calculation of auxiliary floating wire length and submerged trail could result as a function of buoy attitude changes.

It is therefore recommended that:

1. The depth-signal processing circuitry should incorporate corrections for temperature effects.

2. Either the SENSOTEC or CONRAC gages should be used for submarine communications buoys.

3. The alternate blanking valve design be further evaluated for incorporation into the chosendepth gage.

4. The depth transducer should be mounted as close as possible to the point in the buoy where true depth must be accurately determined.

APPENDIX A

TABULATED RESULTS OF THE LEAST-SQUARES FITTING ANALYSIS

Tables 4 to 7 are the results of the least-squares first-order fitting routine as generated by the computer. Tables 4 and 5 contain results for the analysis of temperature effects for 0 to 30 psig (0 to 207 kPa) and 0 to 650 psig (0 to 4.5 MPa) calibrations, respectively. Tables 6 and 7 contain results of the simulated long-term cycling for 0 to 30 psig (0 to 270 kPa) and 0 to 650 psig (0 to 4.5 MPa) calibrations, respectively.

(U) TABLE 4 - LEAST-SQUARES FITTING RESULTS FOR A 0-30 psi (0-207 kPa) CALIBRATION AT VARIOUS TEMPERATURES

TABLE 4a - PRESSURE GAGE EVALUATION 30 psi CALIBRATION CYCLES 1 TO 3 LOW-TEMPERATURE CYCLES -15 DEGREES C

(UNCLASSIFIED)

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                                                              14-AUG-78

    THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B           PAGE  1

GAGE NO. 1  AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A( 1)=      0.115 B( 1)=    -1.108
CORRELATION COEFFICIENT=  1.000
VARIANCE=    0.10   PSI
MAXIMUM DEVIATION=     0.23   PSI
OR   0.04 PER CENT OF FULL SCALE

GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A( 2)=  105.597 B( 2)=  -73.323
CORRELATION COEFFICIENT=  0.998
VARIANCE =    0.66   PSI
MAXIMUM DEVIATION=     1.40   PSI
OR  0.28 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC
MAX PRESSURE = 750 PSI
A( 3)=  146.592 B( 3)=    -2.756
CORRELATION COEFFICIENT=  0.999
VARIANCE=    0.39   PSI
MAXIMUM DEVIATION=     1.02   PSI
OR   0.14 PER CENT OF FULL SCALE

GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 500 PSI
A( 4)=12121.212 B( 4)=     -4.141
CORRELATION COEFFICIENT=  0.663
VARIANCE =  13.20   PSI
MAXIMUM DEVIATION=    10.10   PSI
OR  2.02 PER CENT OF FULL SCALE

GAGE NO. 5  CONRAC
MAX PRESSURE = 500 PSI
A( 5)=     65.143 B( 5)=   -83.308
CORRELATION COEFFICIENT=  1.000
VARIANCE=    0.27   PSI
MAXIMUM DEVIATION=     0.43   PSI
OR   0.09 PER CENT OF FULL SCALE

GAGE NO. 6  ITC NO.1
MAX PRESSURE =1000 PSI
A( 6)= 2259.887 B( 6)=    -0.395
CORRELATION COEFFICIENT=  0.999
VARIANCE =    0.42   PSI
MAXIMUM DEVIATION=     0.90   PSI
OR   0.09 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2
MAX PRESSURE =1000 PSI
A( 7)= 2063.953 B( 7)=    -5.115
CORRELATION COEFFICIENT=  0.999
VARIANCE=    0.41   PSI
MAXIMUM DEVIATION=     0.57   PSI
OR   0.06 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =     0 PSI
A( 0)=      0.000 B( 0)=     0.000
CORRELATION COEFFICIENT=  0.000
VARIANCE =    0.00   PSI
MAXIMUM DEVIATION=     0.00   PSI
OR   0.00 PER CENT OF FULL SCALE
```

(U) TABLE 4 (Continued)

TABLE 4b - PRESSURE GAGE EVALUATION 30 psi CALIBRATION CYCLES 1 TO 4
ROOM-TEMPERATURE CYCLES 24 DEGREES C

(UNCLASSIFIED)

2-AUG-78

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B   PAGE 1

```
GAGE NO. 1  AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A( 1)=     0.113 B( 1)=    -1.176
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.13  PSI
MAXIMUM DEVIATION=      0.30  PSI
OR  0.05 PER CENT OF FULL SCALE

GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A( 2)=  105.773 B( 2)=     0.525
CORRELATION COEFFICIENT=  0.997
VARIANCE =    0.93  PSI
MAXIMUM DEVIATION=      1.41  PSI
OR  0.28 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC
MAX PRESSURE = 750 PSI
A( 3)=  149.533 B( 3)=    -2.199
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.21  PSI
MAXIMUM DEVIATION=      0.40  PSI
OR  0.05 PER CENT OF FULL SCALE

GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 500 PSI
A( 4)=10958.904 B( 4)=    -0.411
CORRELATION COEFFICIENT=  0.940
VARIANCE =    4.20  PSI
MAXIMUM DEVIATION=     12.47  PSI
OR  2.49 PER CENT OF FULL SCALE

GAGE NO. 5  CONRAC
MAX PRESSURE = 500 PSI
A( 5)=   86.430 B( 5)=   -36.070
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.18  PSI
MAXIMUM DEVIATION=      0.30  PSI
OR  0.06 PER CENT OF FULL SCALE

GAGE NO. 6  ITC NO.1
MAX PRESSURE =1000 PSI
A( 6)= 2402.402 B( 6)=     2.312
CORRELATION COEFFICIENT=  0.996
VARIANCE =    1.02  PSI
MAXIMUM DEVIATION=      2.31  PSI
OR  0.23 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2
MAX PRESSURE =1000 PSI
A( 7)= 2133.333 B( 7)=    -2.800
CORRELATION COEFFICIENT=  0.994
VARIANCE=   1.25  PSI
MAXIMUM DEVIATION=      2.13  PSI
OR  0.21 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =    0 PSI
A( 0)=     0.000 B( 0)=     0.000
CORRELATION COEFFICIENT=  0.000
VARIANCE =    0.00  PSI
MAXIMUM DEVIATION=      0.00  PSI
OR  0.00 PER CENT OF FULL SCALE
```

TABLE 4 (Continued)

(U) TABLE 4c - PRESSURE GAGE EVALUATION 30 psi CALIBRATION CYCLES 5
ROOM-TEMPERATURE CYCLES 24 DEGREES C

4-AUG-78

(UNCLASSIFIED)

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B   PAGE 1

```
GAGE NO. 1  AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A( 1)=     0.110 B( 1)=    -0.601
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.23  PSI
MAXIMUM DEVIATION=     0.31  PSI
OR  0.05 PER CENT OF FULL SCALE

GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A( 2)=  100.959 B( 2)=  -70.146
CORRELATION COEFFICIENT=  0.999
VARIANCE =   0.51  PSI
MAXIMUM DEVIATION=     0.51  PSI
OR  0.10 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC
MAX PRESSURE = 750 PSI
A( 3)=  144.404 B( 3)=    -1.047
CORRELATION COEFFICIENT=  0.999
VARIANCE=   0.46  PSI
MAXIMUM DEVIATION=     0.65  PSI
OR  0.09 PER CENT OF FULL SCALE

GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 500 PSI
A( 4)=14705.882 B( 4)=   14.265
CORRELATION COEFFICIENT=  0.996
VARIANCE =   1.14  PSI
MAXIMUM DEVIATION=     1.62  PSI
OR  0.32 PER CENT OF FULL SCALE

GAGE NO. 5  CONRAC
MAX PRESSURE = 500 PSI
A( 5)=   84.368 B( 5)=  -81.857
CORRELATION COEFFICIENT=  0.999
VARIANCE=   0.45  PSI
MAXIMUM DEVIATION=     0.55  PSI
OR  0.11 PER CENT OF FULL SCALE

GAGE NO. 6  ITC NO.1
MAX PRESSURE =1000 PSI
A( 6)= 2298.851 B( 6)=    3.216
CORRELATION COEFFICIENT=  0.996
VARIANCE =   1.21  PSI
MAXIMUM DEVIATION=     1.61  PSI
OR  0.16 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2
MAX PRESSURE =1000 PSI
A( 7)= 2150.538 B( 7)=    -2.473
CORRELATION COEFFICIENT=  0.999
VARIANCE=   0.71  PSI
MAXIMUM DEVIATION=     1.18  PSI
OR  0.12 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =     0 PSI
A( 0)=     0.000 B( 0)=     0.000
CORRELATION COEFFICIENT=  0.000
VARIANCE =   0.00  PSI
MAXIMUM DEVIATION=     0.00  PSI
OR  0.00 PER CENT OF FULL SCALE
```

(U) TABLE 4d - PRESSURE GAGE EVALUATION 30 psi CALIBRATION CYCLES 1 TO 2 HIGH-TEMPERATURE CYCLES 31 DEGREES C

31-JUL-78

(UNCLASSIFIED)

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B   PAGE 1

```
GAGE NO. 1  AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A( 1)=     0.116 B( 1)=    -1.756
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.34  PSI
MAXIMUM DEVIATION=     0.44  PSI
OR  0.07 PER CENT OF FULL SCALE

GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A( 2)=  104.603 B( 2)=  -73.311
CORRELATION COEFFICIENT=  0.998
VARIANCE =   0.72  PSI
MAXIMUM DEVIATION=     0.98  PSI
OR  0.20 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC
MAX PRESSURE = 750 PSI
A( 3)=  130.094 B( 3)=    -1.576
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.13  PSI
MAXIMUM DEVIATION=     0.19  PSI
OR  0.03 PER CENT OF FULL SCALE

GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 500 PSI
A( 4)-10389.611 B( 4)=  -10.649
CORRELATION COEFFICIENT=  0.994
VARIANCE =   1.26  PSI
MAXIMUM DEVIATION=     0.91  PSI
OR  0.18 PER CENT OF FULL SCALE

GAGE NO. 5  CONRAC
MAX PRESSURE = 500 PSI
A( 5)=    39.526 B( 5)=   -37.876
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.16  PSI
MAXIMUM DEVIATION=     0.31  PSI
OR  0.06 PER CENT OF FULL SCALE

GAGE NO. 6  ITC NO.1
MAX PRESSURE =1000 PSI
A( 6)= 2500.000 B( 6)=     2.500
CORRELATION COEFFICIENT=  1.000
VARIANCE =   0.00  PSI
MAXIMUM DEVIATION=     0.00  PSI
OR  0.00 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2
MAX PRESSURE =1000 PSI
A( 7)= 2323.381 B( 7)=    -5.930
CORRELATION COEFFICIENT=  0.997
VARIANCE=   0.92  PSI
MAXIMUM DEVIATION=     1.28  PSI
OR  0.13 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =    0 PSI
A( 0)=     0.000 B( 0)=     0.000
CORRELATION COEFFICIENT=  0.000
VARIANCE =   0.00  PSI
MAXIMUM DEVIATION=     0.00  PSI
OR  0.00 PER CENT OF FULL SCALE
```

TABLE 4 (Continued)

(U) TABLE 4e - PRESSURE GAGE EVALUATION 30 psi CALIBRATION CYCLES 3 TO 4
HIGH-TEMPERATURE CYCLES 38 DEGREES C

31-JUL-75

(UNCLASSIFIED)

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B   PAGE 1

```
GAGE NO. 1  AERO-MECHANICAL            GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 600 PSI                 MAX PRESSURE = 500 PSI
A( 1)=     0.116 B( 1)=    -2.033      A( 2)=  107.009 B( 2)=   -75.530
CORRELATION COEFFICIENT=  0.999        CORRELATION COEFFICIENT=  0.998
VARIANCE=   0.39  PSI                  VARIANCE =    0.73  PSI
MAXIMUM DEVIATION=     0.64  PSI       MAXIMUM DEVIATION=     1.16  PSI
OR  0.11 PER CENT OF FULL SCALE        OR  0.23 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC                   GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 750 PSI                 MAX PRESSURE = 500 PSI
A( 3)=  150.376 B( 3)=    -1.190       A( 4)= 8421.053 B( 4)=    -3.158
CORRELATION COEFFICIENT=  1.000        CORRELATION COEFFICIENT=  0.964
VARIANCE=   0.08  PSI                  VARIANCE =    3.30  PSI
MAXIMUM DEVIATION=     0.09  PSI       MAXIMUM DEVIATION=     3.68  PSI
OR  0.01 PER CENT OF FULL SCALE        OR  0.74 PER CENT OF FULL SCALE

GAGE NO. 5  CONRAC                     GAGE NO. 6  ITC NO.1
MAX PRESSURE = 500 PSI                 MAX PRESSURE =1000 PSI
A( 5)=   90.559 B( 5)=   -88.515       A( 6)= 2547.771 B( 6)=     2.102
CORRELATION COEFFICIENT=  1.000        CORRELATION COEFFICIENT=  0.999
VARIANCE=   0.28  PSI                  VARIANCE =    0.62  PSI
MAXIMUM DEVIATION=     0.69  PSI       MAXIMUM DEVIATION=     2.10  PSI
OR  0.14 PER CENT OF FULL SCALE        OR  0.21 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2                   GAGE NO. 0
MAX PRESSURE =1000 PSI                 MAX PRESSURE =     0 PSI
A( 7)= 2197.802 B( 7)=    -4.231       A( 0)=    0.000 B( 0)=     0.000
CORRELATION COEFFICIENT=  0.992        CORRELATION COEFFICIENT=  0.000
VARIANCE=   1.55  PSI                  VARIANCE =    0.00  PSI
MAXIMUM DEVIATION=     2.36  PSI       MAXIMUM DEVIATION=     0.00  PSI
OR  0.24 PER CENT OF FULL SCALE        OR  0.00 PER CENT OF FULL SCALE
```

TABLE 4 (Continued)

**(U) TABLE 4f - PRESSURE GAGE EVALUATION 30 psi CALIBRATION CYCLES 5 TO 6
HIGH-TEMPERATURE CYCLES 50 DEGREES C**

31-JUL-78

(UNCLASSIFIED)

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B PAGE 1

GAGE NO. 1 AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A(1)= 0.112 B(1)= -1.277
CORRELATION COEFFICIENT= 1.000
VARIANCE= 0.29 PSI
MAXIMUM DEVIATION= 0.85 PSI
OR 0.14 PER CENT OF FULL SCALE

GAGE NO. 2 SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A(2)= 103.842 B(2)= -72.630
CORRELATION COEFFICIENT= 0.999
VARIANCE = 0.57 PSI
MAXIMUM DEVIATION= 1.10 PSI
OR 0.22 PER CENT OF FULL SCALE

GAGE NO. 3 SENSOTEC
MAX PRESSURE = 750 PSI
A(3)= 150.376 B(3)= 0.514
CORRELATION COEFFICIENT= 1.000
VARIANCE= 0.22 PSI
MAXIMUM DEVIATION= 0.29 PSI
OR 0.04 PER CENT OF FULL SCALE

GAGE NO. 4 BELL AND HOWELL
MAX PRESSURE = 500 PSI
A(4)= 9280.743 B(4)= -4.664
CORRELATION COEFFICIENT= 0.967
VARIANCE = 3.16 PSI
MAXIMUM DEVIATION= 4.62 PSI
OR 0.92 PER CENT OF FULL SCALE

GAGE NO. 5 CONRAC
MAX PRESSURE = 500 PSI
A(5)= 38.145 B(5)= -35.264
CORRELATION COEFFICIENT= 1.000
VARIANCE= 0.24 PSI
MAXIMUM DEVIATION= 0.37 PSI
OR 0.07 PER CENT OF FULL SCALE

GAGE NO. 6 ITC NO.1
MAX PRESSURE =1000 PSI
A(6)= 2522.068 B(6)= 0.719
CORRELATION COEFFICIENT= 0.996
VARIANCE = 1.01 PSI
MAXIMUM DEVIATION= 1.74 PSI
OR 0.17 PER CENT OF FULL SCALE

GAGE NO. 7 ITC NO.2
MAX PRESSURE =1000 PSI
A(7)= 2237.136 B(7)= -3.512
CORRELATION COEFFICIENT= 0.990
VARIANCE= 1.73 PSI
MAXIMUM DEVIATION= 2.15 PSI
OR 0.21 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE = 0 PSI
A(0)= 0.000 B(0)= 0.000
CORRELATION COEFFICIENT= 0.000
VARIANCE = 0.00 PSI
MAXIMUM DEVIATION= 0.00 PSI
OR 0.00 PER CENT OF FULL SCALE

(U) TABLE 5 - LEAST-SQUARES FITTING RESULTS FOR A 0-650 psi (0-4.5 MPa) CALIBRATION AT VARIOUS TEMPERATURES

TABLE 5a - PRESSURE GAGE EVALUATION 650 psi CALIBRATION CYCLES 1 TO 3 LOW-TEMPERATURE CYCLES -15 DEGREES C

26-JUL-78

(UNCLASSIFIED)

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B   PAGE 1

GAGE NO. 1 AERO-MECHANICAL
MAX PRESSURE = 650 PSI
A(1)= 0.119 B(1)= -0.500
CORRELATION COEFFICIENT= 1.000
VARIANCE= 1.06 PSI
MAXIMUM DEVIATION= 1.94 PSI
OR 0.30 PER CENT OF FULL SCALE

GAGE NO. 2 SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A(2)= 107.398 B(2)= -78.316
CORRELATION COEFFICIENT= 0.997
VARIANCE = 11.25 PSI
MAXIMUM DEVIATION= 16.57 PSI
OR 3.31 PER CENT OF FULL SCALE

GAGE NO. 3 SENSOTEC
MAX PRESSURE = 750 PSI
A(3)= 149.639 B(3)= -3.214
CORRELATION COEFFICIENT= 1.000
VARIANCE= 0.25 PSI
MAXIMUM DEVIATION= 0.85 PSI
OR 0.11 PER CENT OF FULL SCALE

GAGE NO. 4 BELL AND HOWELL
MAX PRESSURE = 500 PSI
A(4)=12083.274 B(4)= -3.928
CORRELATION COEFFICIENT= 0.994
VARIANCE = 17.99 PSI
MAXIMUM DEVIATION= 19.74 PSI
OR 3.95 PER CENT OF FULL SCALE

GAGE NO. 5 CONRAC
MAX PRESSURE = 500 PSI
A(5)= 87.686 B(5)= -86.696
CORRELATION COEFFICIENT= 1.000
VARIANCE= 0.45 PSI
MAXIMUM DEVIATION= 0.74 PSI
OR 0.15 PER CENT OF FULL SCALE

GAGE NO. 6 ITC NO.1
MAX PRESSURE =1000 PSI
A(6)= 2236.748 B(6)= 0.834
CORRELATION COEFFICIENT= 1.000
VARIANCE = 1.48 PSI
MAXIMUM DEVIATION= 9.37 PSI
OR 0.94 PER CENT OF FULL SCALE

GAGE NO. 7 ITC NO.2
MAX PRESSURE =1000 PSI
A(7)= 2044.317 B(7)= -3.680
CORRELATION COEFFICIENT= 1.000
VARIANCE= 1.45 PSI
MAXIMUM DEVIATION= 2.95 PSI
OR 0.30 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE = 0 PSI
A(0)= 0.000 B(0)= 0.000
CORRELATION COEFFICIENT= 0.000
VARIANCE = 0.00 PSI
MAXIMUM DEVIATION= 0.00 PSI
OR 0.00 PER CENT OF FULL SCALE

TABLE 5 (Continued)

(U) TABLE 5b - PRESSURE GAGE EVALUATION 650 psi CALIBRATION CYCLES 1 TO 4
ROOM-TEMPERATURE CYCLES 24 DEGREES C

2-AUG-78

(UNCLASSIFIED)

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THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B          PAGE  1

GAGE NO. 1  AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A( 1)=     0.115 B( 1)=      0.618
CORRELATION COEFFICIENT=  1.000
VARIANCE=    1.67  PSI
MAXIMUM DEVIATION=     3.32  PSI
OR  0.55 PER CENT OF FULL SCALE

GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A( 2)=  101.120 B( 2)=      1.197
CORRELATION COEFFICIENT=  1.000
VARIANCE =    0.80  PSI
MAXIMUM DEVIATION=     1.49  PSI
OR  0.30 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC
MAX PRESSURE = 750 PSI
A( 3)=  149.855 B( 3)=     -2.318
CORRELATION COEFFICIENT=  1.000
VARIANCE=    0.23  PSI
MAXIMUM DEVIATION=     0.54  PSI
OR  0.07 PER CENT OF FULL SCALE

GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 500 PSI
A( 4)=12613.392 B( 4)=     -3.620
CORRELATION COEFFICIENT=  1.000
VARIANCE =    4.56  PSI
MAXIMUM DEVIATION=    14.22  PSI
OR  2.84 PER CENT OF FULL SCALE

GAGE NO. 5  CONRAC
MAX PRESSURE = 500 PSI
A( 5)=    38.556 B( 5)=   -88.961
CORRELATION COEFFICIENT=  1.000
VARIANCE=    0.41  PSI
MAXIMUM DEVIATION=     0.71  PSI
OR  0.14 PER CENT OF FULL SCALE

GAGE NO. 6  ITC NO.1
MAX PRESSURE =1000 PSI
A( 6)= 2403.954 B( 6)=      3.850
CORRELATION COEFFICIENT=  1.000
VARIANCE =    2.33  PSI
MAXIMUM DEVIATION=     7.73  PSI
OR  0.77 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2
MAX PRESSURE =1000 PSI
A( 7)= 2157.715 B( 7)=     -1.867
CORRELATION COEFFICIENT=  1.000
VARIANCE=    2.05  PSI
MAXIMUM DEVIATION=     6.24  PSI
OR  0.62 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =    0 PSI
A( 0)=     0.000 B( 0)=      0.000
CORRELATION COEFFICIENT=  0.000
VARIANCE =    0.00  PSI
MAXIMUM DEVIATION=     0.00  PSI
OR  0.00 PER CENT OF FULL SCALE
```

TABLE 5 (Continued)

(U) TABLE 5c - PRESSURE GAGE EVALUATION 650 psi CALIBRATION CYCLES 5
ROOM-TEMPERATURE CYCLES 24 DEGREES C

(UNCLASSIFIED)

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                                                                 2-AUG-78

    THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B            PAGE  1

GAGE NO. 1  AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A( 1)=     0.115 B( 1)=     0.740
CORRELATION COEFFICIENT=  1.000
VARIANCE=   1.71  PSI
MAXIMUM DEVIATION=     3.09  PSI
OR  0.51 PER CENT OF FULL SCALE

GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A( 2)=  102.582 B( 2)=  -72.015
CORRELATION COEFFICIENT=  1.000
VARIANCE =   2.52  PSI
MAXIMUM DEVIATION=     5.09  PSI
OR  1.02 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC
MAX PRESSURE = 750 PSI
A( 3)=  149.795 B( 3)=   -1.864
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.32  PSI
MAXIMUM DEVIATION=     0.36  PSI
OR  0.05 PER CENT OF FULL SCALE

GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 500 PSI
A( 4)=12445.483 B( 4)=   14.118
CORRELATION COEFFICIENT=  1.000
VARIANCE =   1.57  PSI
MAXIMUM DEVIATION=     3.90  PSI
OR  0.78 PER CENT OF FULL SCALE

GAGE NO. 5  CONPAC
MAX PRESSURE = 500 PSI
A( 5)=   88.622 B( 5)=  -87.213
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.53  PSI
MAXIMUM DEVIATION=     0.54  PSI
OR  0.11 PER CENT OF FULL SCALE

GAGE NO. 6  ITC NO.1
MAX PRESSURE =1000 PSI
A( 6)= 2335.168 B( 6)=    4.535
CORRELATION COEFFICIENT=  1.000
VARIANCE =   3.43  PSI
MAXIMUM DEVIATION=     5.69  PSI
OR  0.57 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2
MAX PRESSURE =1000 PSI
A( 7)= 2155.639 B( 7)=   -1.489
CORRELATION COEFFICIENT=  1.000
VARIANCE=   2.13  PSI
MAXIMUM DEVIATION=     4.25  PSI
OR  0.42 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =    0 PSI
A( 0)=     0.000 B( 0)=     0.000
CORRELATION COEFFICIENT=  0.000
VARIANCE =   0.00  PSI
MAXIMUM DEVIATION=     0.00  PSI
OR  0.00 PER CENT OF FULL SCALE
```

TABLE 5 (Continued)

(U) TABLE 5d - PRESSURE GAGE EVALUATION 650 psi CALIBRATION CYCLES 1 TO 2
HIGH-TEMPERATURE CYCLES 31 DEGREES C

31-JUL-73

(UNCLASSIFIED)

```
THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B        PAGE  1

GAGE NO. 1  AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A( 1)=     0.115 B( 1)=     0.496
CORRELATION COEFFICIENT=  1.000
VARIANCE=    1.70  PSI
MAXIMUM DEVIATION=     3.23  PSI
OR  0.54 PER CENT OF FULL SCALE

GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A( 2)=  102.474 B( 2)=  -72.077
CORRELATION COEFFICIENT=  1.000
VARIANCE =    2.71  PSI
MAXIMUM DEVIATION=     4.63  PSI
OR  0.93 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC
MAX PRESSURE = 750 PSI
A( 3)=  149.538 B( 3)=   -1.629
CORRELATION COEFFICIENT=  1.000
VARIANCE=    0.16  PSI
MAXIMUM DEVIATION=     0.54  PSI
OR  0.07 PER CENT OF FULL SCALE

GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 500 PSI
A( 4)=11908.779 B( 4)=  -14.017
CORRELATION COEFFICIENT=  1.000
VARIANCE =    2.79  PSI
MAXIMUM DEVIATION=     5.15  PSI
OR  1.03 PER CENT OF FULL SCALE

GAGE NO. 5  CONRAC
MAX PRESSURE = 500 PSI
A( 5)=    36.378 B( 5)=  -37.385
CORRELATION COEFFICIENT=  1.000
VARIANCE=    0.34  PSI
MAXIMUM DEVIATION=     0.38  PSI
OR  0.12 PER CENT OF FULL SCALE

GAGE NO. 6  ITC NO.1
MAX PRESSURE =1000 PSI
A( 6)= 2434.987 B( 6)=    4.191
CORRELATION COEFFICIENT=  1.000
VARIANCE =    1.56  PSI
MAXIMUM DEVIATION=     4.33  PSI
OR  0.43 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2
MAX PRESSURE =1000 PSI
A( 7)= 2172.615 B( 7)=   -3.199
CORRELATION COEFFICIENT=  1.000
VARIANCE=    1.51  PSI
MAXIMUM DEVIATION=     3.32  PSI
OR  0.33 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =    0 PSI
A( 0)=     0.000 B( 0)=    0.000
CORRELATION COEFFICIENT=  0.000
VARIANCE =    0.00  PSI
MAXIMUM DEVIATION=     0.00  PSI
OR  0.00 PER CENT OF FULL SCALE
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TABLE 5 (Continued)

(U) TABLE 5e - PRESSURE GAGE EVALUATION 650 psi CALIBRATION CYCLES 3 TO 4
HIGH-TEMPERATURE CYCLES 38 DEGREES C

(UNCLASSIFIED)

31-JUL-78

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B   PAGE 1

GAGE NO. 1 AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A(1)= 0.114 B(1)= 0.800
CORRELATION COEFFICIENT= 1.000
VARIANCE= 1.90 PSI
MAXIMUM DEVIATION= 3.43 PSI
OR 0.57 PER CENT OF FULL SCALE

GAGE NO. 2 SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A(2)= 102.398 B(2)= -72.057
CORRELATION COEFFICIENT= 1.000
VARIANCE = 2.87 PSI
MAXIMUM DEVIATION= 5.63 PSI
OR 1.13 PER CENT OF FULL SCALE

GAGE NO. 3 SENSOTEC
MAX PRESSURE = 750 PSI
A(3)= 149.864 B(3)= -1.186
CORRELATION COEFFICIENT= 1.000
VARIANCE= 0.11 PSI
MAXIMUM DEVIATION= 0.34 PSI
OR 0.05 PER CENT OF FULL SCALE

GAGE NO. 4 BELL AND HOWELL
MAX PRESSURE = 500 PSI
A(4)=11822.266 B(4)= -12.011
CORRELATION COEFFICIENT= 1.000
VARIANCE = 3.95 PSI
MAXIMUM DEVIATION= 6.21 PSI
OR 1.24 PER CENT OF FULL SCALE

GAGE NO. 5 CONRAC
MAX PRESSURE = 500 PSI
A(5)= 89.063 B(5)= -86.978
CORRELATION COEFFICIENT= 1.000
VARIANCE= 0.33 PSI
MAXIMUM DEVIATION= 0.75 PSI
OR 0.15 PER CENT OF FULL SCALE

GAGE NO. 6 ITC NO.1
MAX PRESSURE =1000 PSI
A(6)= 2465.124 B(6)= 3.559
CORRELATION COEFFICIENT= 1.000
VARIANCE = 1.49 PSI
MAXIMUM DEVIATION= 3.56 PSI
OR 0.36 PER CENT OF FULL SCALE

GAGE NO. 7 ITC NO.2
MAX PRESSURE =1000 PSI
A(7)= 2200.605 B(7)= -3.013
CORRELATION COEFFICIENT= 1.000
VARIANCE= 1.76 PSI
MAXIMUM DEVIATION= 3.59 PSI
OR 0.36 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE = 0 PSI
A(0)= 0.000 B(0)= 0.000
CORRELATION COEFFICIENT= 0.000
VARIANCE = 0.00 PSI
MAXIMUM DEVIATION= 0.00 PSI
OR 0.00 PER CENT OF FULL SCALE

TABLE 5 (Continued)

(U) TABLE 5f - PRESSURE GAGE EVALUATION 650 psi CALIBRATION CYCLES 5 TO 6
HIGH-TEMPERATURE CYCLES 50 DEGREES C

31-JUL-78

(UNCLASSIFIED)

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B   PAGE 1

GAGE NO. 1 AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A(1)= 0.113 B(1)= 1.527
CORRELATION COEFFICIENT= 1.000
VARIANCE= 2.00 PSI
MAXIMUM DEVIATION= 3.68 PSI
OR 0.61 PER CENT OF FULL SCALE

GAGE NO. 2 SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A(2)= 102.040 B(2)= -71.881
CORRELATION COEFFICIENT= 1.000
VARIANCE = 3.28 PSI
MAXIMUM DEVIATION= 5.77 PSI
OR 1.15 PER CENT OF FULL SCALE

GAGE NO. 3 SENSOTEC
MAX PRESSURE = 750 PSI
A(3)= 149.855 B(3)= 0.512
CORRELATION COEFFICIENT= 1.000
VARIANCE= 0.17 PSI
MAXIMUM DEVIATION= 0.27 PSI
OR 0.04 PER CENT OF FULL SCALE

GAGE NO. 4 BELL AND HOWELL
MAX PRESSURE = 500 PSI
A(4)=11775.692 B(4)= -11.125
CORRELATION COEFFICIENT= 1.000
VARIANCE = 2.39 PSI
MAXIMUM DEVIATION= 2.43 PSI
OR 0.49 PER CENT OF FULL SCALE

GAGE NO. 5 CONRAC
MAX PRESSURE = 500 PSI
A(5)= 89.343 B(5)= -86.954
CORRELATION COEFFICIENT= 1.000
VARIANCE= 0.42 PSI
MAXIMUM DEVIATION= 0.73 PSI
OR 0.15 PER CENT OF FULL SCALE

GAGE NO. 6 ITC NO.1
MAX PRESSURE =1000 PSI
A(6)= 2467.676 B(6)= 2.413
CORRELATION COEFFICIENT= 1.000
VARIANCE = 4.95 PSI
MAXIMUM DEVIATION= 12.52 PSI
OR 1.25 PER CENT OF FULL SCALE

GAGE NO. 7 ITC NO.2
MAX PRESSURE =1000 PSI
A(7)= 2208.763 B(7)= -2.071
CORRELATION COEFFICIENT= 1.000
VARIANCE= 5.10 PSI
MAXIMUM DEVIATION= 12.55 PSI
OR 1.25 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE = 0 PSI
A(0)= 0.000 B(0)= 0.000
CORRELATION COEFFICIENT= 0.000
VARIANCE = 0.00 PSI
MAXIMUM DEVIATION= 0.00 PSI
OR 0.00 PER CENT OF FULL SCALE

(U) TABLE 6 - LEAST-SQUARES FITTING RESULTS FOR A 0-30 psi (0-207 kPa) CALIBRATION AT VARIOUS TEMPERATURES

TABLE 6a - PRESSURE GAGE EVALUATION 30 psi CALIBRATION CYCLES 1 LONG-TERM CYCLING END OF FIRST WEEK AT 24 DEGREES C

(UNCLASSIFIED)

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                                                              22-AUG-78

   THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B           PAGE  1

GAGE NO. 1  AERO-MECHANICAL            GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 600 PSI                 MAX PRESSURE = 500 PSI
A( 1)=    0.114 B( 1)=    -1.472       A( 2)=  107.296 B( 2)=  -75.343
CORRELATION COEFFICIENT=  1.000        CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.10  PSI                  VARIANCE =    0.33  PSI
MAXIMUM DEVIATION=      0.14  PSI      MAXIMUM DEVIATION=      0.56  PSI
OR  0.02 PER CENT OF FULL SCALE        OR  0.11 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC                   GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 750 PSI                 MAX PRESSURE = 500 PSI
A( 3)=  150.376 B( 3)=    -0.639       A( 4)=16666.667 B( 4)=   18.333
CORRELATION COEFFICIENT=  1.000        CORRELATION COEFFICIENT=  0.921
VARIANCE=    0.03  PSI                 VARIANCE =    4.03  PSI
MAXIMUM DEVIATION=      0.11  PSI      MAXIMUM DEVIATION=      3.33  PSI
OR  0.02 PER CENT OF FULL SCALE        OR  0.67 PER CENT OF FULL SCALE

GAGE NO. 5  CONRAC                     GAGE NO. 6  ITC NO.1
MAX PRESSURE = 500 PSI                 MAX PRESSURE =1000 PSI
A( 5)=    38.028 B( 5)=  -36.761       A( 6)= 8547.005 B( 6)= -175.385
CORRELATION COEFFICIENT=  1.000        CORRELATION COEFFICIENT=  0.756
VARIANCE=    0.03  PSI                 VARIANCE =   10.15  PSI
MAXIMUM DEVIATION=      0.07  PSI      MAXIMUM DEVIATION=   11.71  PSI
OR  0.01 PER CENT OF FULL SCALE        OR  1.17 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2                   GAGE NO. 0
MAX PRESSURE =1000 PSI                 MAX PRESSURE =     0 PSI
A( 7)= 7067.133 B( 7)= -192.562        A( 0)=     0.000 B( 0)=     0.000
CORRELATION COEFFICIENT=  0.723        CORRELATION COEFFICIENT=  0.000
VARIANCE=   12.33  PSI                 VARIANCE =    0.00  PSI
MAXIMUM DEVIATION=    15.30  PSI       MAXIMUM DEVIATION=      0.00  PSI
OR  1.53 PER CENT OF FULL SCALE        OR  0.00 PER CENT OF FULL SCALE

*K

END OF EXECUTION
CPU TIME: 1.52  ELAPSED TIME: 14:24.55
EXIT
```

TABLE 6 (Continued)

(U) TABLE 6b - PRESSURE GAGE EVALUATION 30 psi CALIBRATION CYCLES 2
LONG-TERM CYCLING END OF SECOND WEEK AT 24 DEGREES C

(UNCLASSIFIED)

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                                                          23-AUG-78

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B          PAGE 1

GAGE NO. 1  AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A( 1)=     0.114 B( 1)=    -1.520
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.15  PSI
MAXIMUM DEVIATION=     0.27  PSI
OR  0.04 PER CENT OF FULL SCALE

GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A( 2)=  103.203 B( 2)=  -73.275
CORRELATION COEFFICIENT=  0.999
VARIANCE =   0.53  PSI
MAXIMUM DEVIATION=     0.41  PSI
OR  0.08 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC
MAX PRESSURE = 750 PSI
A( 3)=  149.311 B( 3)=    -0.617
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.14  PSI
MAXIMUM DEVIATION=     0.14  PSI
OR  0.02 PER CENT OF FULL SCALE

GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 500 PSI
A( 4)=12500.000 B( 4)=    13.750
CORRELATION COEFFICIENT=  1.000
VARIANCE =   0.00  PSI
MAXIMUM DEVIATION=     0.00  PSI
OR  0.00 PER CENT OF FULL SCALE

GAGE NO. 5  CONRAC
MAX PRESSURE = 500 PSI
A( 5)=   87.945 B( 5)=   -86.730
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.02  PSI
MAXIMUM DEVIATION=     0.04  PSI
OR  0.01 PER CENT OF FULL SCALE

GAGE NO. 6  ITC NO.1
MAX PRESSURE =1000 PSI
A( 6)=11921.896 B( 6)= -233.736
CORRELATION COEFFICIENT=  0.353
VARIANCE =  31.96  PSI
MAXIMUM DEVIATION=    31.00  PSI
OR  3.10 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2
MAX PRESSURE =1000 PSI
A( 7)= 7601.573 B( 7)= -199.692
CORRELATION COEFFICIENT=  0.451
VARIANCE=  23.17  PSI
MAXIMUM DEVIATION=    23.03  PSI
OR  2.30 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =    0 PSI
A( 0)=     0.000 B( 0)=     0.000
CORRELATION COEFFICIENT=  0.000
VARIANCE =   0.00  PSI
MAXIMUM DEVIATION=     0.00  PSI
OR  0.00 PER CENT OF FULL SCALE
```

TABLE 6 (Continued)

(U) TABLE 6c - PRESSURE GAGE EVALUATION 30 psi CALIBRATION CYCLES 3
LONG-TERM CYCLING END OF THIRD WEEK AT 24 DEGREES C

(UNCLASSIFIED)

```
                                                          21-AUG-78

 THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B          PAGE  1

GAGE NO. 1  AERO-MECHANICAL           GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 600 PSI                MAX PRESSURE = 500 PSI
A( 1)=     0.113 B( 1)=    -1.442     A( 2)=  101.947 B( 2)=  -71.737
CORRELATION COEFFICIENT=  1.000       CORRELATION COEFFICIENT=  0.997
VARIANCE=   0.20  PSI                 VARIANCE =    0.69  PSI
MAXIMUM DEVIATION=     0.37  PSI      MAXIMUM DEVIATION=     1.17  PSI
OR  0.06 PER CENT OF FULL SCALE       OR  0.23 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC                  GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 750 PSI                MAX PRESSURE = 500 PSI
A( 3)=  149.830 B( 3)=    -0.322      A( 4)=17031.254 B( 4)=   18.258
CORRELATION COEFFICIENT=  1.000       CORRELATION COEFFICIENT=  0.972
VARIANCE=   0.12  PSI                 VARIANCE =    1.43  PSI
MAXIMUM DEVIATION=     0.17  PSI      MAXIMUM DEVIATION=     1.73  PSI
OR  0.02 PER CENT OF FULL SCALE       OR  0.35 PER CENT OF FULL SCALE

GAGE NO. 5  CONPAC                    GAGE NO. 6  ITC NO.1
MAX PRESSURE = 500 PSI                MAX PRESSURE =1000 PSI
A( 5)=    87.603 B( 5)=   -86.295     A( 6)= 7526.545 B( 6)= -130.244
CORRELATION COEFFICIENT=  1.000       CORRELATION COEFFICIENT=  0.801
VARIANCE=   0.13  PSI                 VARIANCE =    7.00  PSI
MAXIMUM DEVIATION=     0.41  PSI      MAXIMUM DEVIATION=    10.35  PSI
OR  0.08 PER CENT OF FULL SCALE       OR  1.04 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2                  GAGE NO. 0
MAX PRESSURE =1000 PSI                MAX PRESSURE =     0 PSI
A( 7)= 5407.474 B( 7)= -205.274       A( 0)=     0.000 B( 0)=     0.000
CORRELATION COEFFICIENT=  0.612       CORRELATION COEFFICIENT=  0.000
VARIANCE=  12.09  PSI                 VARIANCE =    0.00  PSI
MAXIMUM DEVIATION=    19.84  PSI      MAXIMUM DEVIATION=     0.00  PSI
OR  1.98 PER CENT OF FULL SCALE       OR  0.00 PER CENT OF FULL SCALE
```

TABLE 6 (Continued)

(U) TABLE 6d - PRESSURE GAGE EVALUATION 30 psi CALIBRATION CYCLES 4
LONG-TERM CYCLING END OF FOURTH WEEK AT 24 DEGREES C

21-AUG-78

(UNCLASSIFIED)

```
THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B          PAGE  1

GAGE NO. 1  AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A( 1)=     0.113 B( 1)=    -1.376
CORRELATION COEFFICIENT=  1.000
VARIANCE=    0.16  PSI
MAXIMUM DEVIATION=     0.22  PSI
OR  0.04 PER CENT OF FULL SCALE

GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A( 2)=  100.363 B( 2)=  -71.004
CORRELATION COEFFICIENT=  0.997
VARIANCE =    0.67  PSI
MAXIMUM DEVIATION=     1.37  PSI
OR  0.27 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC
MAX PRESSURE = 750 PSI
A( 3)=  149.920 B( 3)=    -0.561
CORRELATION COEFFICIENT=  1.000
VARIANCE=    0.18  PSI
MAXIMUM DEVIATION=     0.34  PSI
OR  0.04 PER CENT OF FULL SCALE

GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 500 PSI
A( 4)=12420.680 B( 4)=   15.075
CORRELATION COEFFICIENT=  0.996
VARIANCE =    0.54  PSI
MAXIMUM DEVIATION=     0.86  PSI
OR  0.17 PER CENT OF FULL SCALE

GAGE NO. 5  CONRAC
MAX PRESSURE = 500 PSI
A( 5)=    37.789 B( 5)=  -86.507
CORRELATION COEFFICIENT=  1.000
VARIANCE=    0.11  PSI
MAXIMUM DEVIATION=     0.16  PSI
OR  0.03 PER CENT OF FULL SCALE

GAGE NO. 6  ITC NO.1
MAX PRESSURE =1000 PSI
A( 6)= 6975.091 B( 6)=  -74.566
CORRELATION COEFFICIENT=  0.562
VARIANCE =  13.79  PSI
MAXIMUM DEVIATION=   16.45  PSI
OR  1.65 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2
MAX PRESSURE =1000 PSI
A( 7)= 8625.858 B( 7)= -182.679
CORRELATION COEFFICIENT=  0.[illegible]
VARIANCE=  13.56  PSI
MAXIMUM DEVIATION=   23.67  PSI
OR  2.37 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =    0 PSI
A( 0)=     0.000 B( 0)=     0.000
CORRELATION COEFFICIENT=  0.000
VARIANCE =    0.00  PSI
MAXIMUM DEVIATION=     0.00  PSI
OR  0.00 PER CENT OF FULL SCALE
```

(U) TABLE 7 - LEAST-SQUARES FITTING RESULTS FOR A 650 psi (0-4.5 MPa) CALIBRATION AT VARIOUS TEMPERATURES

(U) TABLE 7a - PRESSURE GAGE EVALUATION 650 psi CALIBRATION CYCLES 1 LONG-TERM CYCLING END OF FIRST WEEK AT 24 DEGREES C

(UNCLASSIFIED)

23-AUG-78

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B   PAGE 1

GAGE NO. 1 AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A(1)=   0.115 B(1)=   0.092
CORRELATION COEFFICIENT= 1.000
VARIANCE=   1.46 PSI
MAXIMUM DEVIATION=   2.17 PSI
OR 0.36 PER CENT OF FULL SCALE

GAGE NO. 3 SENSOTEC
MAX PRESSURE = 750 PSI
A(3)= 149.780 B(3)=   -0.639
CORRELATION COEFFICIENT= 1.000
VARIANCE=   0.13 PSI
MAXIMUM DEVIATION=   0.29 PSI
OR 0.04 PER CENT OF FULL SCALE

GAGE NO. 5 CONRAC
MAX PRESSURE = 500 PSI
A(5)=   58.685 B(5)=   -57.341
CORRELATION COEFFICIENT= 1.000
VARIANCE=   0.35 PSI
MAXIMUM DEVIATION=   0.58 PSI
OR 0.12 PER CENT OF FULL SCALE

GAGE NO. 7 ITC NO.2
MAX PRESSURE =1000 PSI
A(7)= 2135.509 B(7)=   -30.198
CORRELATION COEFFICIENT= 0.998
VARIANCE=   12.65 PSI
MAXIMUM DEVIATION=   32.53 PSI
OR 3.25 PER CENT OF FULL SCALE

GAGE NO. 2 SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A(2)= 102.020 B(2)=   -71.432
CORRELATION COEFFICIENT= 1.000
VARIANCE =   2.54 PSI
MAXIMUM DEVIATION=   5.31 PSI
OR 1.06 PER CENT OF FULL SCALE

GAGE NO. 4 BELL AND HOWELL
MAX PRESSURE = 500 PSI
A(4)=12615.514 B(4)=   21.556
CORRELATION COEFFICIENT= 0.999
VARIANCE =   7.29 PSI
MAXIMUM DEVIATION=   10.20 PSI
OR 2.04 PER CENT OF FULL SCALE

GAGE NO. 6 ITC NO.1
MAX PRESSURE =1000 PSI
A(6)= 2439.846 B(6)=   -18.741
CORRELATION COEFFICIENT= 0.996
VARIANCE =   13.61 PSI
MAXIMUM DEVIATION=   34.20 PSI
OR 3.42 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =   0 PSI
A(0)=   0.000 B(0)=   0.000
CORRELATION COEFFICIENT= 0.000
VARIANCE =   0.00 PSI
MAXIMUM DEVIATION=   0.00 PSI
OR 0.00 PER CENT OF FULL SCALE

TABLE 7 (Continued)

(U) TABLE 7b - PRESSURE GAGE EVALUATION 650 psi CALIBRATION CYCLES 2
LONG-TERM CYCLING END OF SECOND WEEK AT 24 DEGREES C

23-AUG-78

(UNCLASSIFIED)

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B   PAGE 1

```
GAGE NO. 1  AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A( 1)=    0.115 B( 1)=    -0.146
CORRELATION COEFFICIENT=  1.000
VARIANCE=   1.52  PSI
MAXIMUM DEVIATION=     2.85  PSI
OR  0.48 PER CENT OF FULL SCALE

GAGE NO. 2  SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A( 2)=  102.130 B( 2)=   -72.404
CORRELATION COEFFICIENT=  1.000
VARIANCE =   2.78  PSI
MAXIMUM DEVIATION=     5.86  PSI
OR  1.17 PER CENT OF FULL SCALE

GAGE NO. 3  SENSOTEC
MAX PRESSURE = 730 PSI
A( 3)=  149.752 B( 3)=    -0.723
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.13  PSI
MAXIMUM DEVIATION=     0.32  PSI
OR  0.04 PER CENT OF FULL SCALE

GAGE NO. 4  BELL AND HOWELL
MAX PRESSURE = 500 PSI
A( 4)=12528.876 B( 4)=    14.256
CORRELATION COEFFICIENT=  1.000
VARIANCE =   1.82  PSI
MAXIMUM DEVIATION=     2.30  PSI
OR  0.46 PER CENT OF FULL SCALE

GAGE NO. 5  CONPAC
MAX PRESSURE = 500 PSI
A( 5)=   88.680 B( 5)=   -87.853
CORRELATION COEFFICIENT=  1.000
VARIANCE=   0.36  PSI
MAXIMUM DEVIATION=     0.62  PSI
OR  0.12 PER CENT OF FULL SCALE

GAGE NO. 6  ITC NO.1
MAX PRESSURE =1000 PSI
A( 6)= 2472.240 B( 6)=   -26.383
CORRELATION COEFFICIENT=  0.997
VARIANCE =  16.66  PSI
MAXIMUM DEVIATION=    38.88  PSI
OR  3.89 PER CENT OF FULL SCALE

GAGE NO. 7  ITC NO.2
MAX PRESSURE =1000 PSI
A( 7)= 2184.955 B( 7)=   -30.088
CORRELATION COEFFICIENT=  0.998
VARIANCE=  13.44  PSI
MAXIMUM DEVIATION=    33.93  PSI
OR  3.39 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =    0 PSI
A( 0)=    0.000 B( 0)=     0.000
CORRELATION COEFFICIENT=  0.000
VARIANCE =   0.00  PSI
MAXIMUM DEVIATION=     0.00  PSI
OR  0.00 PER CENT OF FULL SCALE
```

TABLE 7 (Continued)

(U) TABLE 7c - PRESSURE GAGE EVALUATION 650 psi CALIBRATION CYCLES 3
LONG-TERM CYCLING END OF THIRD WEEK AT 24 DEGREES C

21-AUG-78

(UNCLASSIFIED)

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B   PAGE 1

GAGE NO. 1 AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A(1)= 0.116 B(1)= -0.490
CORRELATION COEFFICIENT= 1.000
VARIANCE= 1.57 PSI
MAXIMUM DEVIATION= 2.91 PSI
OR 0.49 PER CENT OF FULL SCALE

GAGE NO. 2 SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A(2)= 101.630 B(2)= -71.693
CORRELATION COEFFICIENT= 1.000
VARIANCE = 2.28 PSI
MAXIMUM DEVIATION= 5.16 PSI
OR 1.03 PER CENT OF FULL SCALE

GAGE NO. 3 SENSOTEC
MAX PRESSURE = 750 PSI
A(3)= 149.743 B(3)= -0.591
CORRELATION COEFFICIENT= 1.000
VARIANCE= 0.16 PSI
MAXIMUM DEVIATION= 0.36 PSI
OR 0.05 PER CENT OF FULL SCALE

GAGE NO. 4 BELL AND HOWELL
MAX PRESSURE = 500 PSI
A(4)=12514.401 B(4)= 14.984
CORRELATION COEFFICIENT= 1.000
VARIANCE = 1.36 PSI
MAXIMUM DEVIATION= 1.68 PSI
OR 0.34 PER CENT OF FULL SCALE

GAGE NO. 5 CONRAC
MAX PRESSURE = 500 PSI
A(5)= 88.631 B(5)= -87.639
CORRELATION COEFFICIENT= 1.000
VARIANCE= 0.34 PSI
MAXIMUM DEVIATION= 0.59 PSI
OR 0.12 PER CENT OF FULL SCALE

GAGE NO. 6 ITC NO.1
MAX PRESSURE =1000 PSI
A(6)= 2441.123 B(6)= -19.920
CORRELATION COEFFICIENT= 0.998
VARIANCE = 13.69 PSI
MAXIMUM DEVIATION= 22.31 PSI
OR 2.23 PER CENT OF FULL SCALE

GAGE NO. 7 ITC NO.2
MAX PRESSURE =1000 PSI
A(7)= 2200.930 B(7)= -33.403
CORRELATION COEFFICIENT= 0.998
VARIANCE= 13.75 PSI
MAXIMUM DEVIATION= 23.16 PSI
OR 2.32 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE = 0 PSI
A(0)= 0.000 B(0)= 0.000
CORRELATION COEFFICIENT= 0.000
VARIANCE = 0.00 PSI
MAXIMUM DEVIATION= 0.00 PSI
OR 0.00 PER CENT OF FULL SCALE

TABLE 7 (Continued)

(U) TABLE 7d - PRESSURE GAGE EVALUATION 650 psi CALIBRATION CYCLES 4
LONG-TERM CYCLING END OF FOURTH WEEK AT 24 DEGREES C

21-AUG-78

(UNCLASSIFIED)

THE FITTING FUNCTION IS: PRESSURE= A*VOLTAGE + B   PAGE 1

GAGE NO. 1 AERO-MECHANICAL
MAX PRESSURE = 600 PSI
A(1)=   0.116 B(1)=   -0.298
CORRELATION COEFFICIENT= 1.000
VARIANCE=   1.52 PSI
MAXIMUM DEVIATION=   2.09 PSI
OR 0.35 PER CENT OF FULL SCALE

GAGE NO. 2 SPARTON-SOUTHWEST
MAX PRESSURE = 500 PSI
A(2)= 101.345 B(2)= -71.674
CORRELATION COEFFICIENT= 1.000
VARIANCE =   2.31 PSI
MAXIMUM DEVIATION=   5.05 PSI
OR 1.01 PER CENT OF FULL SCALE

GAGE NO. 3 SENSOTEC
MAX PRESSURE = 750 PSI
A(3)= 149.760 B(3)=   -0.623
CORRELATION COEFFICIENT= 1.000
VARIANCE=   0.19 PSI
MAXIMUM DEVIATION=   0.40 PSI
OR 0.05 PER CENT OF FULL SCALE

GAGE NO. 4 BELL AND HOWELL
MAX PRESSURE = 500 PSI
A(4)=12526.545 B(4)=   14.974
CORRELATION COEFFICIENT= 1.000
VARIANCE =   0.62 PSI
MAXIMUM DEVIATION=   1.51 PSI
OR 0.30 PER CENT OF FULL SCALE

GAGE NO. 5 CONRAC
MAX PRESSURE = 500 PSI
A(5)=   88.641 B(5)= -87.675
CORRELATION COEFFICIENT= 1.000
VARIANCE=   0.35 PSI
MAXIMUM DEVIATION=   0.58 PSI
OR 0.12 PER CENT OF FULL SCALE

GAGE NO. 6 ITC NO.1
MAX PRESSURE =1000 PSI
A(6)= 2335.176 B(6)=   -9.747
CORRELATION COEFFICIENT= 0.999
VARIANCE =   9.66 PSI
MAXIMUM DEVIATION=   19.35 PSI
OR 1.94 PER CENT OF FULL SCALE

GAGE NO. 7 ITC NO.2
MAX PRESSURE =1000 PSI
A(7)= 2155.597 B(7)= -23.967
CORRELATION COEFFICIENT= 0.999
VARIANCE= 11.01 PSI
MAXIMUM DEVIATION=   23.03 PSI
OR 2.30 PER CENT OF FULL SCALE

GAGE NO. 0
MAX PRESSURE =   0 PSI
A(0)=   0.000 B(0)=   0.000
CORRELATION COEFFICIENT= 0.000
VARIANCE =   0.00 PSI
MAXIMUM DEVIATION=   0.00 PSI
OR 0.00 PER CENT OF FULL SCALE

APPENDIX B

DERIVATION AND APPLICATION OF EQUATIONS FOR DEPTH-GAGE MOUNTING LOCATION ANALYSIS

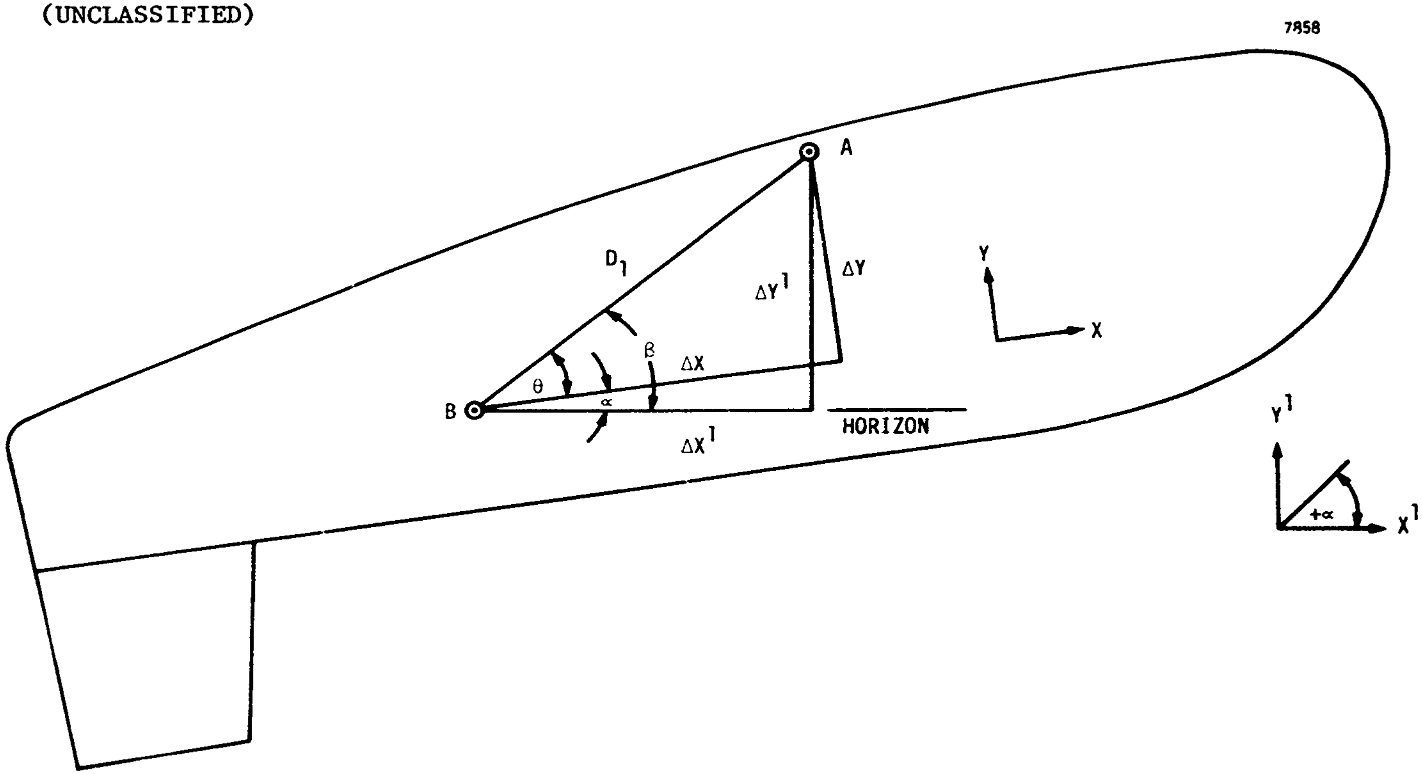
The purpose of this analysis is to determine the effect of buoy pitch and roll on the relative positions of two points (A&B) representing the locations of the depth gage and the point in the buoy to which buoy depth is referenced. The effects of buoy pitch and roll on relative positions are illustrated by Figures 27 and 28, respectively. Table 8 lists pitch angle as a function of speed for the POSEIDON buoy.

(U) TABLE 8 - POSEIDON PITCH ANGLES

(UNCLASSIFIED)

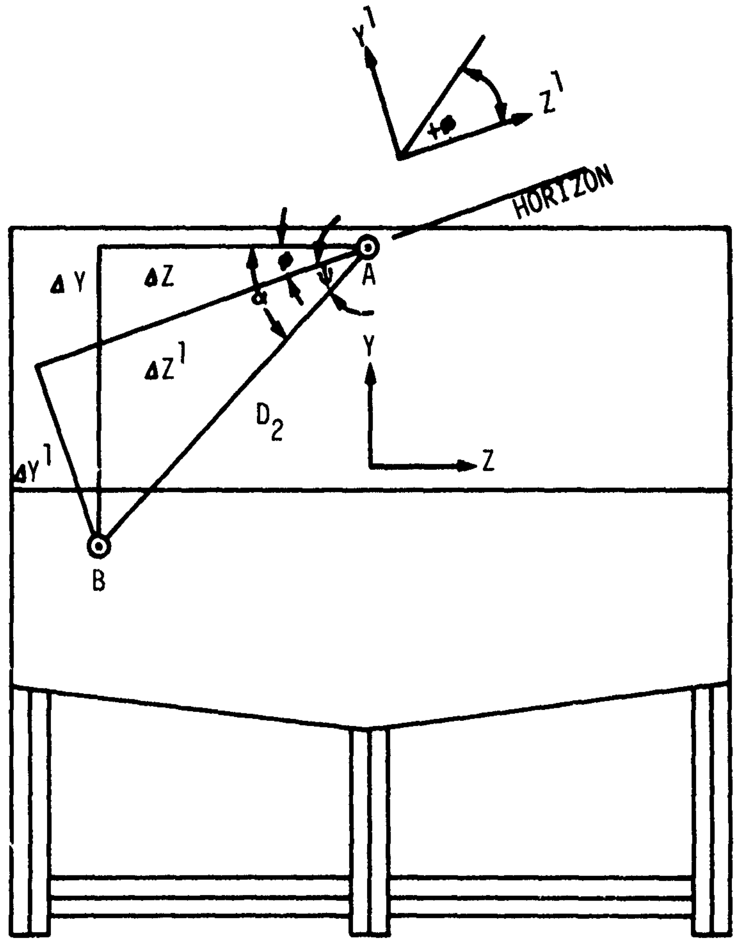
Speed knots	Pitch Angle degrees
0	5.0
2	6.0
4	7.0
6	9.9
8	11.0
10	11.5
12	12.0
13	12.0
14	12.0
15	12.0

(UNCLASSIFIED)



(U) Figure 27 - Geometry for Depth Error Analysis Due to Pitch Angle

(UNCLASSIFIED)



(U) Figure 28 - Geometry for Depth Error Analysis Due to Roll Angle

The errors due to depth gage mounting location are defined by the following equations. The pitch-angle and roll-angle errors are developed separately.*

The components of pitch displacement between points A and B are:

$$\Delta X = XB - XA$$
$$\Delta Y = YB - YA \qquad (2)$$

Since the pitch displacement between points A and B does not vary with buoy attitude:

$$(\Delta X^1)^2 + (\Delta Y^1)^2 = (D_1)^2 \qquad (3)$$

Combining the equation with the relationship:

$$\frac{\Delta Y^1}{\Delta X^1} = \text{Tan } \beta \qquad (4)$$

The distance between points A and B in pitch referenced to the X^1-Y^1-Z^1 coordinate system are:

$$\Delta X^1 = D_1 \cos \beta$$
$$\Delta Y^1 = D_1 \sin \beta \qquad (5)$$

The components of roll displacement between points A and B are:

$$\Delta Z = ZB - ZA \qquad (6)$$

Since the roll displacement between points A and B does not vary with buoy attitude:

$$(\Delta Z^1)^2 + (\Delta Y^1)^2 = (D_2)^2 \qquad (7)$$

Combining this equation with the relationship:

$$\frac{\Delta Y^1}{\Delta Z^1} = \text{Tan } \psi \qquad (8)$$

---

* For symbol definition refer to Notation listing

The distance between points A and B in roll referenced to the X^1-Y^1-Z^1 coordinate system are:

$$\Delta Z^1 = D_2 \cos \phi \qquad (9)$$
$$\Delta Y^1 = D_2 \sin \phi$$

Combining the equations for pitch and roll, the components of distance between points A and B for any pitch and roll angle are:

$$\Delta X^1 = D_1 \cos \qquad (10)$$

$$\Delta Y^1 = D_1 \sin \beta + D_2 \sin \psi \qquad (11)$$

$$\Delta Z^1 = D_2 \cos \phi \qquad (12)$$

The difference in relative positions of points A and B between the buoy at zero pitch and roll and the buoy at some arbitrary pitch and roll angle is:

$$X \text{ diff} = D_1 (\cos \beta - \cos \phi) \qquad (13)$$

$$Y \text{ diff} = D_1 (\sin \beta - \sin \phi) - D_2 (\sin \delta - \sin \psi) \qquad (14)$$

$$Z \text{ diff} = D_2 (\cos \psi - \cos \delta) \qquad (15)$$

An example of the depth gage mounting location error analysis is provided to lead the reader through the problem.

For the POSEIDON buoy, taking Point 1 as the top of the auxiliary wire antenna mast and Point 2 as the present location of the Depth and Destruct cannister:

$\Delta X = 5 - 39.625 = -34.625$ in. (-0.88 m)

$\Delta Y = 10 - 27.4 = -17.4$ in. (-0.44 m)

$\Delta Z = 0$

$\theta = 206.6^\circ$

$D_1 = 38.75$ in. (0.98 m)

$\delta = 270^\circ$

$D_2 = 17.4$ in. (0.44 m)

$\beta = \alpha + 206.68^\circ$

$\psi = \phi + 270^\circ$

X diff = 38.75 (cos β+ .893) in. (0.98 (cos β+ .843) m)

Y diff = 38.75 (sin β+ .449) - 17.4 (-1-sin ψ psi) in.

Z diff = 17.4 (cos ψ - 0) in. (0.44 (cos ψ 0) m)

Assume max pitch angle of 15 degrees, max roll angle of 2 degrees

X diff = 5.66 in. (0.14 m)

Y diff = -8.35 in. (-0.21 m)

Z diff = 0.60 in. (0.01 m)

Assuming a speed of 6 knots and a depth of 8 ft (2.5 m) the parametric partial derivatives are: (from Reference 1):

1. For antenna floating length, $\frac{\Delta FL}{\Delta Y}$ = 0.929 ft/in. (0.111 m/cm)

2. For submerged antenna trail, $\frac{\Delta XS}{\Delta Y}$ = 0.463 ft/in. (0.055 m/cm)

Then, using $\Delta Y = Y^1 = \Delta Y$ + Y diff = 25.75 in. (-0.65 m)

ΔFL = floating length error = -25.75 (0.929) = 23.92 ft (-7.29 m)

ΔXL = submerged trail error = -25.75 (0.463) = -11.92 ft (-3.63 m)

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